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84-IN. PROPELLANT CARTRIDGES AND GRAINS

Volume I - Technical Discussion

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Prepared for

AIR FORCE ROCKET PROPULSION LABORATORY
Director of Science and Technology
Air Force Systems Command
Edwards Air Force Base, CA 93523

NOTICES

FOREWARD

This report was submitted by United Technologies/Chemical Systems Division, P.O. Box 358, Sunnyvale, CA 94086, under Contract No. F04611-76-C-0010, Job Order No. 305909 JM with the Air Force Rocket Propulsion Laboratory, Edwards AFB, CA 93523.

This report has been reviewed by the Information Office/XOJ and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations. This technical report has been reviewed and is approved for publication; it is unclassified and suitable for general public release.

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This report is presented in three volumes:
- Volume I - Technical Discussion
- Volume II - Propellant Test Data
- Volume III - Appendices

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

HTPB Propellant
High Solids Loaded Propellant
UTP-18,803A
ELSH Loaded Cartridges
CHAR Loaded Cartridges
Propellant Characterization
84-Inch Cartridge

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This document reports the results obtained from casting a total of 30 84-inch cartridges with UTP-18,803A propellant (90% solids, 21% aluminum, HTPB). Both ballistic and mechanical property data obtained during the production of over 730,000 lbs of propellant is presented. Documentation for propellant production is provided.

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1.0 INTRODUCTION

Design requirements for advanced ICBMs dictate the use of higher performance solid rocket motors than used for current missile systems. These higher performance motors will (1) use advanced propellants with increased solids loading, (2) exhibit higher flame temperatures, and (3) operate at relatively high chamber pressures. Therefore, the environment faced by nozzle and TVC components of the advanced motors will be far more severe than that of current systems.

To properly evaluate the performance of these advanced designs, these components must be evaluated in tests at sufficient scale and with sufficiently severe operating environments to realistically simulate the final application. To meet this end, AFRPL has developed test motors to provide relatively inexpensive testing of large components. These motors, the 84-in. CHAR motor and the Super HIPPO series, use refurbishable cartridge-loaded propellant grains to minimize refurbishment time and test costs. The propellant for these cartridges is provided by AFRPL-selected contractors.

CSD was selected to provide the AFRPL with a total of 20 loaded ELSH and ten loaded 84-in. CHAR cartridges under contract No. F04611-76-C-0010. CSD cast all 30 grains with its UTP-18,803A propellant, a 90% solids, 21% aluminized HTPB formulation. The propellant was cast in GFE cartridges which were insulated with ORCO-9250 silica-asbestos rubber and lined with CSD's UTL-0040A liner. CSD produced 137 400-gal batches of UTP-18,803A, representing over 730,000 lb of propellant, in fulfillment of the requirements of contract No. F04611-76-C-0010.

This document, presented in three volumes, summarizes the procedures and techniques used in the propellant production (volume I); provides the propellant characterization and reproducibility data obtained from the series of 13 individual production runs completed (volume II); and provides the propellant and propellant processing specifications and the cartridge processing procedures used for casting UTP-18,803A (volume III).

2.0 OBJECTIVE

The objective of this program was to design, fabricate, and deliver to AFRPL refurbishable loaded cartridge propellant grains suitable for testing of advanced ballistic missile nozzle components and materials in a realistic propellant environment.

3.0 SUMMARY

The objective of this program was accomplished as a four-phase program from November 1975 through October 1977. Phases I and III consisted of the design and analysis of the cartridge loaded propellant grains for the ELSH and 84-in. CHAR motors, respectively. Delivery of the specific loaded grains to the AFRPL was completed in phase II (20 ELSH) and in phase IV (ten 84-in. CHAR).

The program effort encompassed the grain design and analysis for the ELSH and 84-in. CHAR motors; the design and fabrication of the casting tooling; propellant characterization; and delivery to AFRPL of 20 ELSH loaded cartridges, ten 84-in. cartridges, all ELSH and CHAR casting tooling, 113 15-lb BATES loaded cartridges and nozzles, and 57 70-lb BATES loaded cartridges and nozzles.

The propellant used for casting the ELSH and CHAR grains was UTP-18,803A, CSD's 90% solids, 21% aluminum, HTPB (R-45M) propellant. The liner system used in conjunction with this propellant was UTL-0040A.

Table 1 presents a summary, by production run, of the loaded cartridges cast. The following paragraphs present an overview of the propellant and liner characteristics as identified from this effort. Section 4.0 of this volume, in conjunction with volume II (propellant processing data) and volume III (appendices), presents a detailed discussion of the processing and quality control methods and data for propellant production.

3.1 UTP-18,803A PROPELLANT CHARACTERISTICS

3.1.1 Formulation

Table 2 shows the formulation of UTP-18,803A; table 3 summarizes some of the propellant's key properties. It should be noted that this formulation retains in excess of 20% strain capability down to -65°F.

TABLE 1. DELIVERABLE LOADED CARTRIDGE SUMMARY

Production Run No.	Cast Date	Propellant Batch Identification	ELSH Cartridges Cast Part No.	ELSH Cartridges Cast Serial No.	CHAR Cartridges Cast Part No.	CHAR Cartridges Cast Serial No.	15-lb BATES	70-lb BATES
1	9-10 Apr 76	400-1454 to 400-1465	C11479-01-01* C11479-02-01	2579-01 2579-02	C12185-01-01	2579-01	12	6
2	28-30 Apr 76	400-1468 to 400-1479	C11479-01-01† C11479-03-01†	2579-03 2579-04	C12185-01-01† C12185-03-01†	2579-02 2579-03	12	6
3	10-11 May 76	400-1480 to 400-1491	C11479-01-01† C11479-03-01†	2579-05 2579-06	C12185-01-01† C12185-03-01†	2579-04 2579-05	12	6
2A	8-9 July 76	400-1495 to 400-1503	C11479-01-01* C11479-03-01	2579-07 2579-08			9	3
3A	22-23 July 76	400-1505 to 400-1515	C11479-01-01 C11479-03-01	2579-09 2579-10	C12185-02-01 C12185-03-01	2579-06 2579-07	12	6
4	10-12 Aug 76	400-1516 to 400-1526	C11479-03-01 C11479-02-01	2579-11 2579-12	C12185-02-01 C12185-03-01	2579-08 2579-09	12	6
5	24-26 Aug 76	400-1527 to 400-1537	C11479-01-01 C11479-01-01	2579-13 2579-14	C12185-03-01	2579-11	10	5
6	15-16 Sept 76	400-1539 to 400-1543			C12185-01-01 C12185-02-01	2579-10 2579-12	5	2
7	5-7 Oct 76	400-1546 to 400-1557	C11479-02-01* C11479-03-01*	2579-15 2579-16	C12185-01-01	2579-13	12	6
8	8-9 June 77	400-1574 to 400-1582	C11479-01-01 C11479-03-01	2579-17 2579-18			9	3
9	2-3 Aug 77	400-1588 to 400-1600	C11479-01-01 C11479-02-01	2579-19 2579-20	C12185-01-01	2579-14	6	4
10	30-31 Aug 77	400-1606 to 400-1615	C11479-01-01 C11479-01-01	2579-21 2579-22			6	4
11	28-29 Sept 77	400-1620 to 400-1629	C11479-01-01 C11479-02-01	2579-23 2579-24			3	3

*X-ray inspected

†Grains not delivered to AFRPL

TABLE 2. FORMULATION OF UTP-18,803A PROPELLANT

T2404R

Ingredient	Function	CSD Specification/ Manufacturer	Manufacturer Designation	Nominal Equivalent	Nominal Formulation by Wt,%	Weight Tolerance Limits,%
HTPB	Binder	ARCO	BDR-45M	1.0	6.67**	-
Isophorone diisocyanate	Curative	Thorson Chemical	IPDI	0.85	0.48**	-
Iso-decyl pelargonate	Plasticizer	Emery Industries	Emolein 2911 (IDP)		2.60	0.2
PRO-TECH®	Antioxidant	CSD	2705		0.10	0.05
HX-752	Bonding agent	3M Company	HX-752		0.15	0.07
Aluminum	Fuel	40DS-40702	MD101		21.0	0.4
Ammonium perchlorate	Oxidizer	40DS-40701	200μ*		44.85	1.0
Ammonium perchlorate	Oxidizer	40DS-40701	8μ†		24.15	

*The unground ammonium perchlorate shall conform to 40DS-40701, type II except the material shall be manufactured by a rotary rounded process.

†Particle size of ground ammonium perchlorate shall be controlled by CSD Quality Control Laboratory Methods and Procedures No. QC-J-703.

**For information only; may be adjusted to optimize mechanical properties.

TABLE 3. PROPERTIES OF UTP-18,803A PROPELLANT

T2405

Theoretical properties		Ballistic Properties (for 66/34 Unground/Ground ratio)	
I^{o}_{sps}, sec	264.3	Burn rate (1,000 psi), in./sec	0.41
C*, ft/sec	5,172	LSBR (1,000 psi)	0.46
Density, lb/in.^{3}	0.0666	Pressure exponent	0.51
T_c, ^oF	6,250	Temperature coefficient, π_k	0.104%/^oF
Oxidation ratio	1.33		

Processing Characteristics		Hazard Properties	
End-of-mix viscosity at 140^oF		DOT classification	Class B
1.0 sec^{-1} shear rate, kps	5.7	Mil classification	Class 2
5,000 dynes/cm^2, kps	5.7	Critical impact	
Pot life at 140^oF, hr	>12	velocity, ft/sec	528

Uniaxial properties (Mix 5-1707)

Temperature, ^oF	Pressure, psia	Strain Rate, in./in./min	$\sigma_m{}^c$, psi	$\epsilon_m{}^c$, %	ϵ_r, %	E_o, psi
70	14.7	0.74	118	37	38	503
70	1,000	90.5	660	54	61	2,026
135	14.7	0.74	89	36	37	388
0	14.7	0.74	195	44	46	889
-30	14.7	0.74	287	49	42	2,927
-65	14.7	0.74	560	23	30	8,236

3.1.2 Rheological Properties

The rheological properties of UTP-18,803A propellant are shown in figures 1 through 3. This propellant is virtually Newtonian; in view of its very low viscosity and Newtonian behavior, it exhibits outstanding castability.

A commonly used criterion for the potlife of rubber-base composite propellants is the time to reach an apparent viscosity of 60 kps at 5,000 dynes/cm^2. Since a plot of log viscosity versus time is usually linear for HTPB propellants, the data plotted in figure 3 suggest a potlife in excess of 12 hr for UTP-18,803A.

3.1.3 Ballistic Characteristics

UTP-18,803A has been fired in a variety of motors ranging from CSD's 4-lb burning rate test motor through AFRPL's 15- and 70-lb BATES motors, the 84-in. CHAR motor, and the ELSH motor. The correspondence between burning rates measured in CSD's 4-lb motor and AFRPL's BATES and 84-in. CHAR motors has been checked repeatedly; the burning rates in the motors are indistinguishable (figure 4).

As illustrated in table 4, the burning rate reproducibility of UTP-18,803A was extremely good. The one standard deviation was consistently in the 1.4% range for the last series of production runs (comparing to 2.0% for Minuteman, 0.9% for Titan, and 1.2% for Algol) following a hardware redesign aimed at improving the 4-lb motor reproducibility. Volume II of the document presents a compilation of the test data used in generating this data summary.

The temperature coefficient of UTP-18,803A propellant was measured in 4-lb motors from 32° to 128°F. The data of figure 5 resulted in a calculated π_k of 0.104%/°F over this temperature range.

The burning rate of UTP-18,803A propellant can be varied within fairly broad limits by manipulating the unground/ground AP ratio (including particle size distribution) in the bimodal blend. Figure 6 shows burning rate data obtained in 4-lb motors over a range of grind ratios from 55/45 to 70/30.

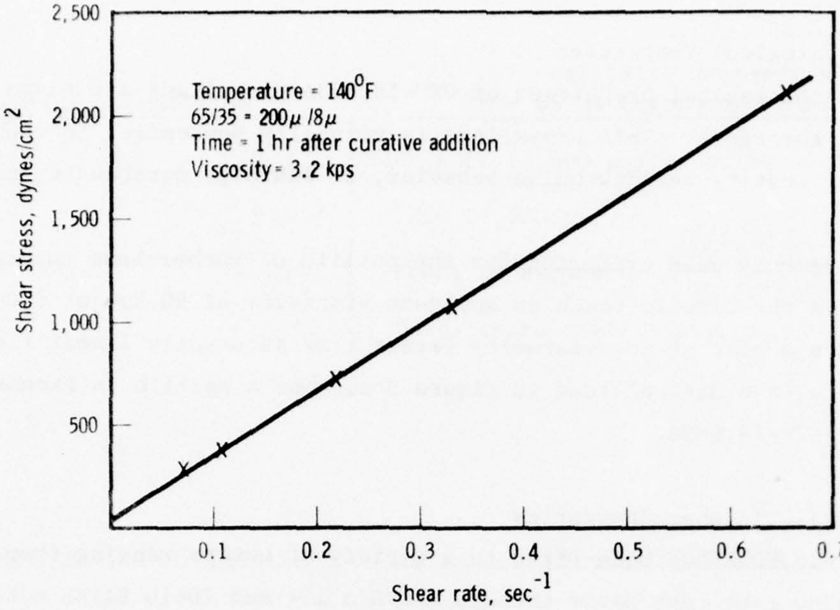

Figure 1. Rheological Properties of UTP-18,803A

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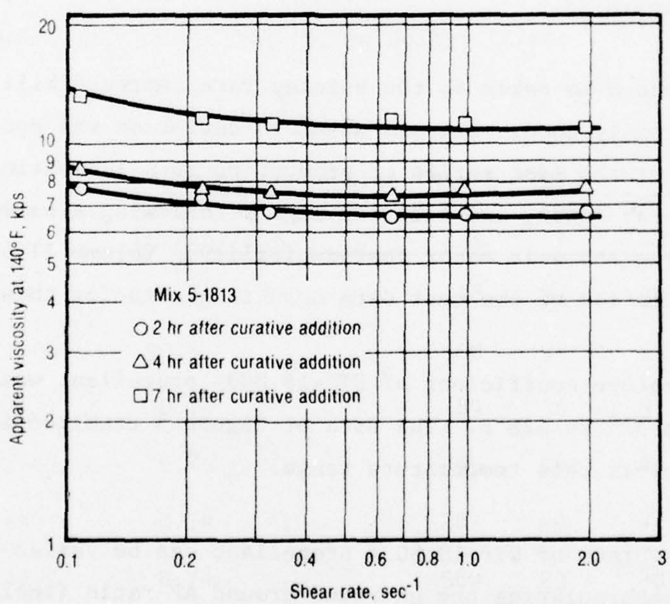

Figure 2. Rheological Properties of UTP-18,803A

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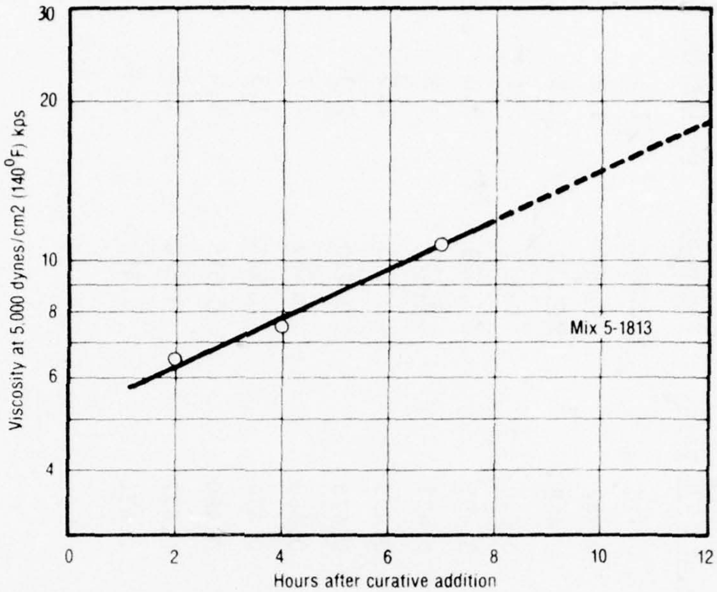

Figure 3. Potlife Data for UTP-18,803A

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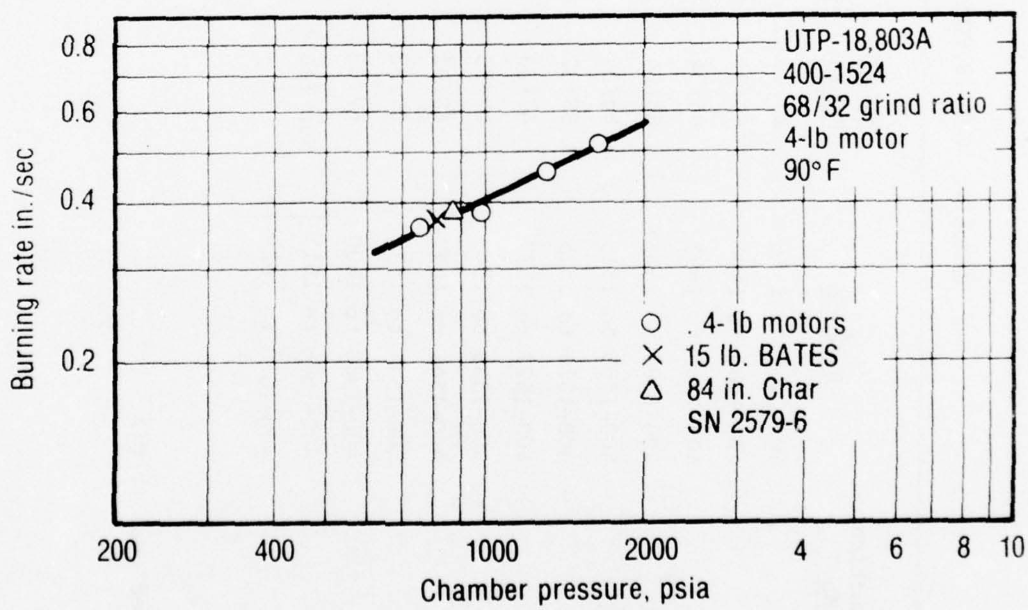

Figure 4. Motor Scaleup, UTP-18,803A

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TABLE 4. UTP-18,803A 4-LB BURNING RATE SUMMARY

T2416

Production Run No.	Batches	Grind Ratio	NCO/OH	Burning Rate at 1400 psia	Pressure Exponent	One Standard Deviation, %
2	400-1468 to 1476	65/35	0.85	0.498	0.537	2.1
3	400-1480 to 1484	65/35	0.85	0.487	0.504	1.9
3	400-1485 to 1491	66/34	0.85	0.488	0.471	1.5
2A	400-1495 to 1503*	66/34	0.85	0.500	0.517	2.1
3A	400-1505 to 1515	66/34	0.82	0.495	0.529	2.0
4	400-1516 to 1525	68/32	0.82	0.472	0.473	1.3
5	400-1527 to 1537	67/33	0.81	0.493	0.475	1.5
6	400-1539 to 1543	67/33	0.81	0.475	0.450	2.3
7	400-1546 to 1557	68/32	0.82	0.480	0.469	1.7
8	400-1574 to 1582	67/33	0.81	0.474	0.525	1.3
9	400-1588 to 1600	67/33	0.81	0.480	0.556	1.4
10	400-1606 to 1615	See Table 21	0.81	0.477	0.522	1.4
11	400-1620 to 1629		0.81	0.474	0.510	1.4

*Aged fuel premix

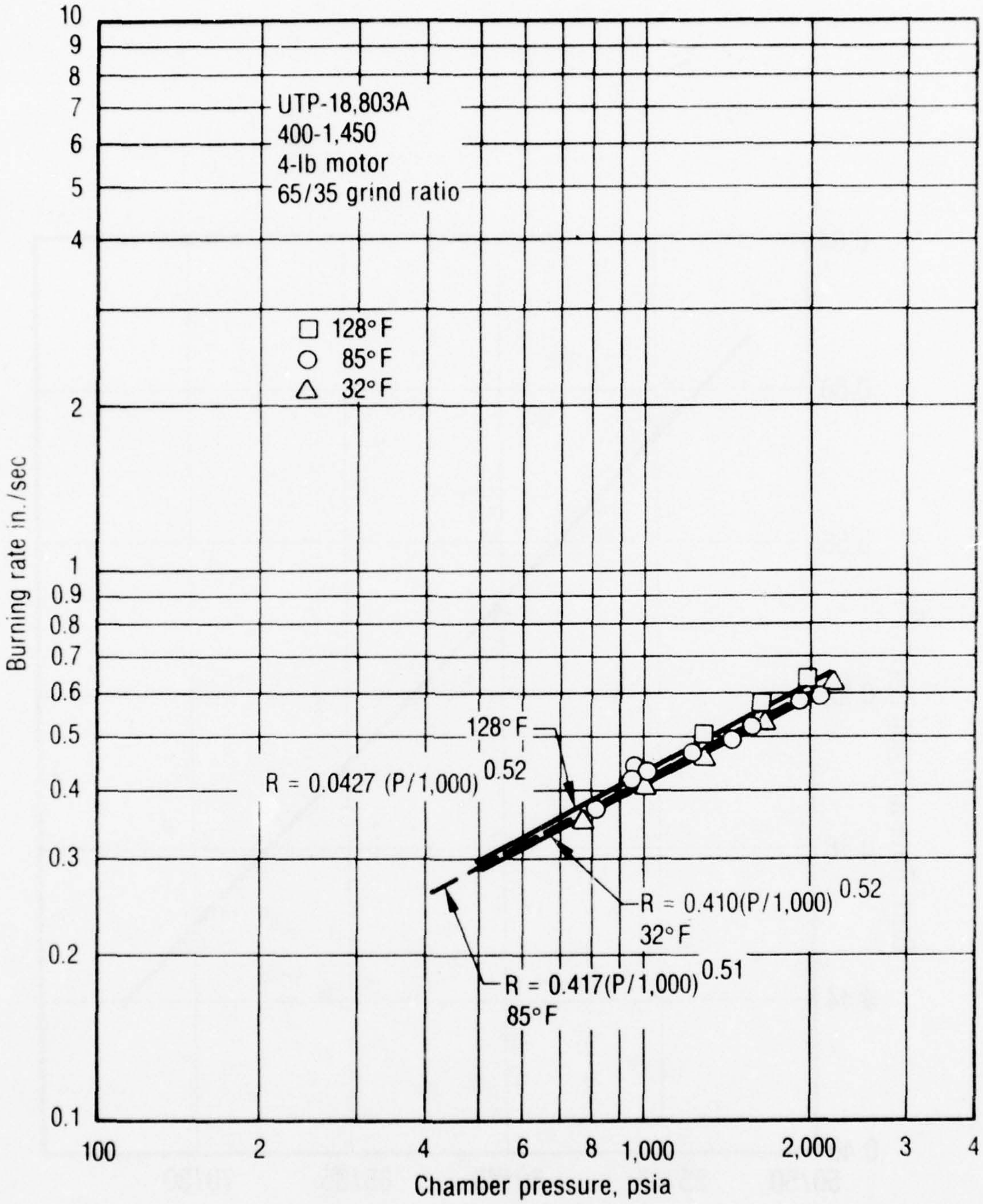

Figure 5. UTP-18,803A Temperature Sensitivity

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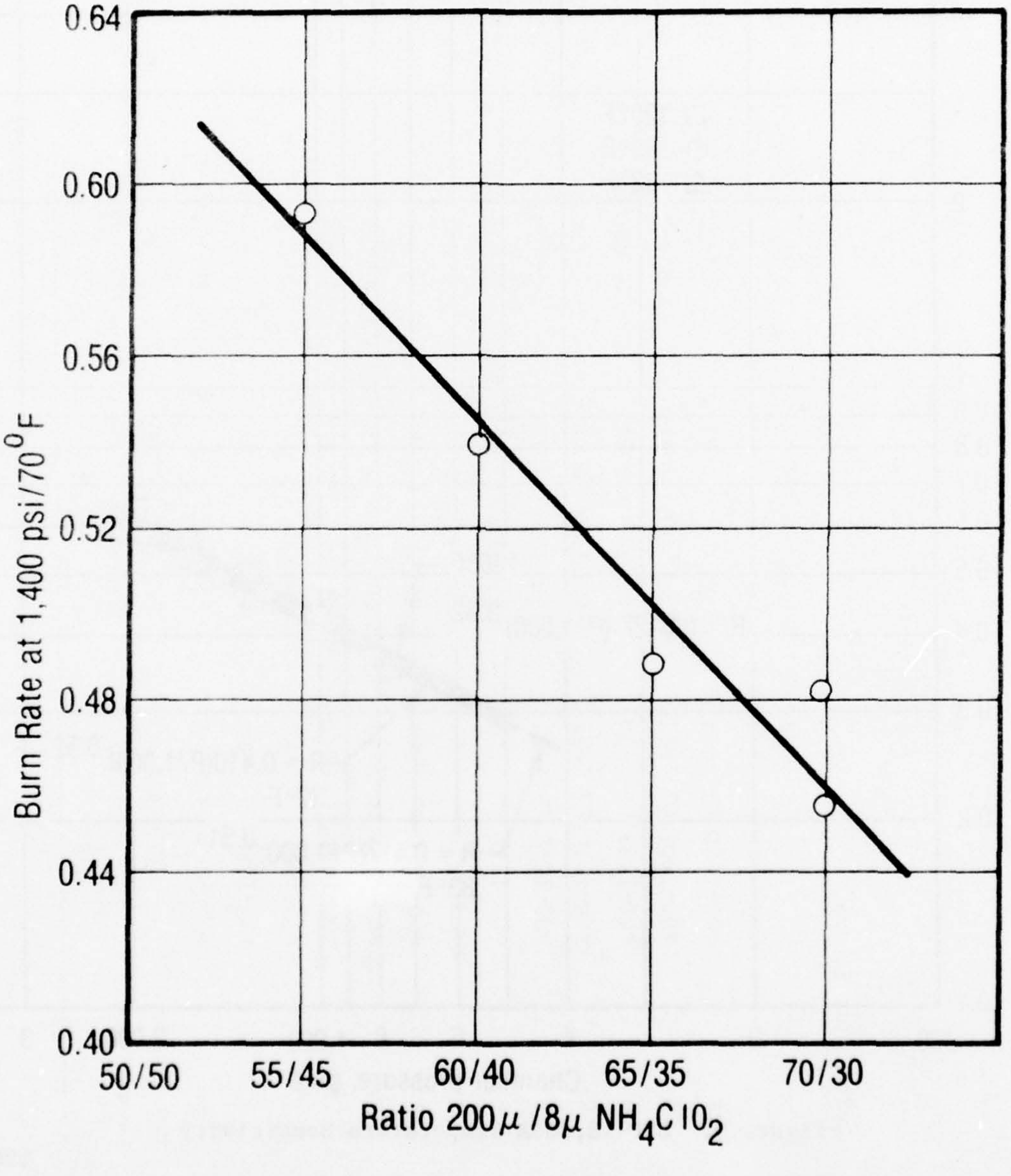

Figure 6. Burning Rate as a Function of Grind Ratio for UTP-18,803A

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The majority of mixes during the ELSH production were made at a 66/34 blend ratio, but the propellant specification allows for adjustment of this ratio to fine tune the burning rate with different AP grinds as dictated by the particle size distribution of both the ground and unground AP.

3.1.4 Correlation of AP Particle Size Distributions with Burning Rate

During the initial phases of processing UTP-18,803A, it became evident that, while the AP grind ratio could be used in a gross sense to set the propellant burning rate (e.g., 70/30 versus 65/35), it could not, of itself, be used to fine tune the burning rate. When considering minor changes in grind ratio (e.g., 67/33 versus 66/34), the variation in burning rate was not necessarily consistent with what would be expected. The key to the fine tuning process was to determine the particle size distribution of both the ground and unground AP, to calculate a particle mean diameter, and then to use this parameter in establishing a precise burning rate.

Four parameters which describe the AP particle distribution yielded reasonable correlations for burning rate control: D_{32}, $D_{3.5-2.5}$, D_{43}, and D_{rate}. Diameter D_{32} is the surface mean diameter and has been used in industry to calculate AP specific surface area. Diameter D_{43} is the weight or volume median diameter which has been successfully correlated with burning rate by Hercules and Thiokol. The $D_{3.5-2.5}$ and D_{rate} diameters are particle distribution diameters derived by Miller of Hercules which were successfully correlated with noncatalyzed HTPB propellant burning rates.

Under this contract, CSD demonstrated the viability of using D_{43} as the propellant burning rate control parameter. Particle size distributions were obtained for the unground and ground AP (see volume II, section 3.0, for particle size distribution data). The particle size distribution for the unground AP was obtained by Tyler Screen analysis, while the particle size distribution for the ground AP was obtained by MSA. These data were then used to calculate the particle distribution diameters described above. A least-squares regression was calculated for each particle diameter

versus 4-lb motor, 90°F burning rates. A summary of these regressions is presented in table 5 and illustrated in figure 7. Once the D_{43} vs propellant burning rate correlation was established, CSD successfully used D_{43} to control the propellant burning rate under production conditions for UTP-18,803A.

3.1.5 Physical Properties

Table 6 presents a summary of the primary propellant physical properties of UTP-18,803A monitored during the series of full-scale production runs.

Volume II of this document presents a compilation of the data obtained under this effort which were used in the summary presented in table 6.

3.1.6 Hazards

Laboratory sensitivity data for UTP-18,803A (table 7) show this propellant to be similar to the majority of workhorse composite propellants. The propellant has been classified as Military class 2, DOT class B by the Bureau of Explosives, as would be expected for this composition.

The critical impact velocity (CIV) measured in the shotgun/quickness test is used as a criterion of DDT susceptibility in class 7 propellants, but is not generally considered meaningful for class 2 zerocard propellants with large critical diameters; however, for reference, the CIV of UTP-18,803A has been determined as 528 ft/sec. Based on data developed by Thiokol under contract No. F04611-72-C-0048, the critical diameter of 90% solids HTPB propellant such as UTP-18,803A is expected to be approximately 20 in.

3.1.7 Analog Motor Testing

CSD conducted a series of tests on four analog motors which were subscale models of the ELSH loaded cartridge. A discussion of these test results is given in section 4.1.2.2.3. These tests demonstrated that the propellant/liner/cartridge system was more than structurally adequate for the conditions of storage, transportation, and thermal cycling specified in the contract.

TABLE 5. SUMMARY OF GROUND AND UNGROUND AP DISTRIBUTION DIAMETER CORRELATIONS WITH BURNING RATE

	Unground				Ground						Ground and Unground	
	67/33 grind		68/32 grind		65/35 grind		66/34 grind		68/32 grind			
	Correlation Coefficient	S_e, in./sec	Correlation Coefficient	S_e, in./sec	Correlation coefficient	S_e, in./sec	Correlation Coefficient	S_e, in./sec	Correlation Coefficient	S_e, in./sec	Correlation Coefficient	S_e, in./sec
Arithmetic mean, d_{10}	0.22	0.012	-0.09	0.007	-0.203	0.006	0.293	0.012	-0.55	0.007	-0.355	0.012
Linear mean diameter, d_{21}	-0.11	0.01	-0.067	0.007	-0.113	0.006	0.329	0.012	-0.603	0.007	-0.374	0.012
Mean weight diameter, d_{30}	-0.074	0.012	-0.084	0.007	-0.109	0.006	-0.335	0.12	-0.630	0.007	-0.436	0.012
Surface mean diameter, d_{32}	-0.725	0.008	-0.488	0.006	0.154	0.006	0.344	0.012	-0.725	0.006	-0.569	0.010
Diameter, $d_{3.5-2.5}$	-0.746	0.008	-0.500	0.006	0.246	0.006	0.277	0.012	-0.775	0.006	-0.8411	0.007
Weight mean diameter, d_{43}	-0.735	0.008	-0.446	0.006	0.137	0.006	0.185	0.012	-0.767	0.006	-0.894	0.0058
Diameter, d_{rate}	-0.746	0.008	-0.514	0.006	0.281	0.006	0.303	0.012	-0.766	0.006	-0.7532	0.0086

*Standard error of estimate, S_e

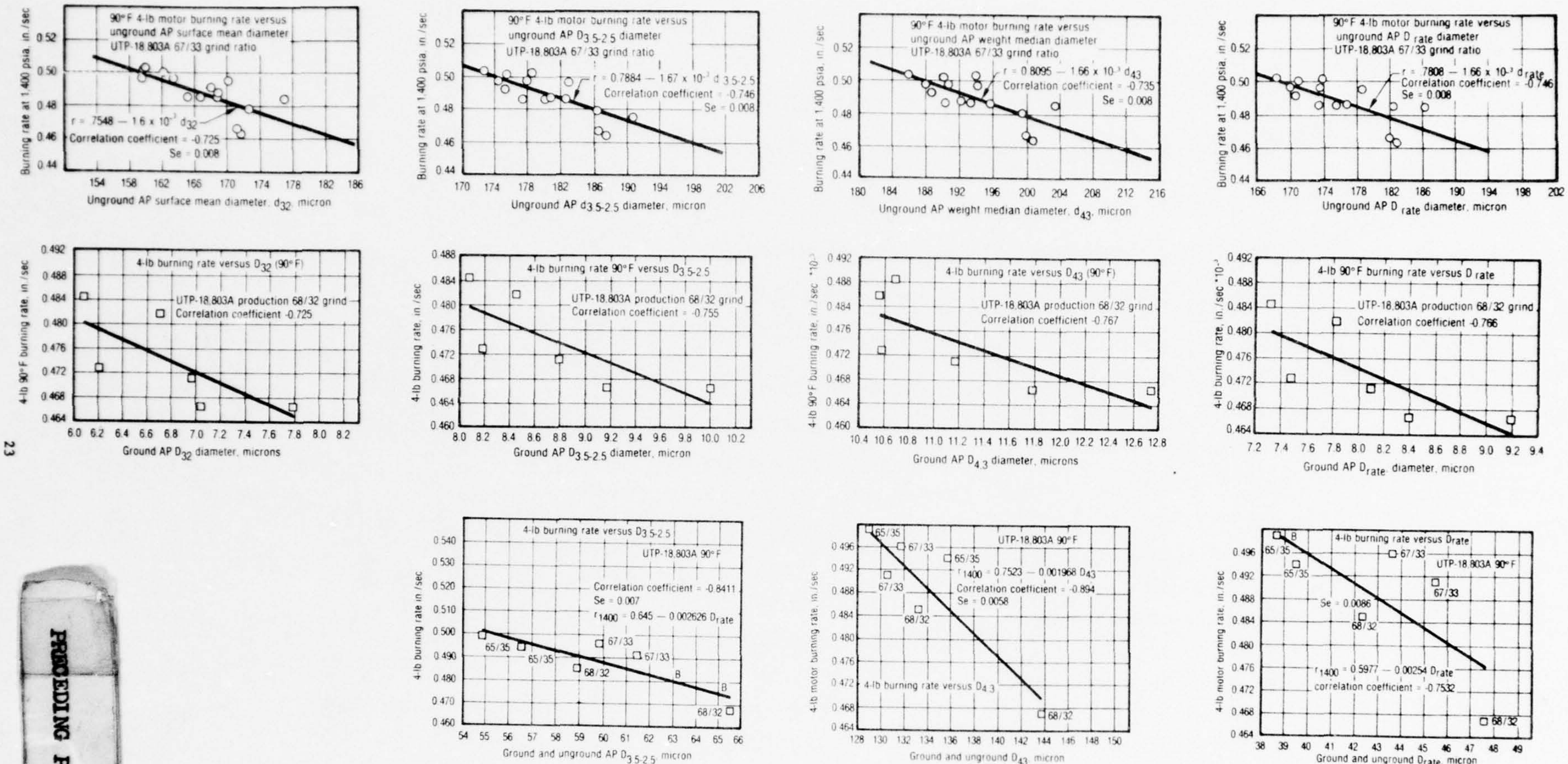

Figure 7. AP Particle Size Distribution Correlation with Burning Rate

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TABLE 6. UTP-18,803A QC PROCESSING AND PHYSICAL PROPERTIES

T2417

Production Run No.	Batch	Grind Ratio	NCO/OH Ratio	Wt % IPDI* $\bar{X}$	Wt % IPDI* Sx	Viscosity* Kp @ 5000 dynes/cm^2 $\bar{X}$	Viscosity* Kp @ 5000 dynes/cm^2 Sx	Max Corrected Stress, $\sigma^c m$, psi $\bar{X}$	Max Corrected Stress, $\sigma^c m$, psi Sx	Max Corrected Strain, $\epsilon^c m$, % $\bar{X}$	Max Corrected Strain, $\epsilon^c m$, % Sx	Initial Tangent Modulus, E_o, psi $\bar{X}$	Initial Tangent Modulus, E_o, psi Sx
2	400-1468 to 1479	65/35	0.85	0.374	0.005	6.57	1.12	125	8.9	29.8	3.6	821	158
3	1480 to 1484	65/35	0.85	0.372	0.001	4.98	0.7	149	9.6	33.0	2.9	957	105
3	1485 to 1491	66/34	0.85	0.371	0.007	6.1	1.67	147	5.1	35.9	2.3	984	132
2A	1495 to 1503**	66/34	0.85	0.403	0.011	6.6	1.1	174	5.2	27.0	2.4	1540	125
3A	1505 to 1515	66/34	0.82	0.389	0.001	5.84	1.5	124	9.3	32.9	2.9	778	144
4	1516 to 1526	68/32	0.82	0.359	0.003	4.56	0.6	114	2.5	36.7	3.5	575	69.5
5	1527 to 1537	67/33	0.81	0.377	0.001	5.27	0.9	103	2.2	35.8	2.1	619	88
6	1539 to 1543	67/33	0.81	0.386	0.009	5.73	1.4	103	10	37.2	6.3	453	74
7	1546 to 1557	68/32	0.82	0.384	0.010	5.46	0.8	119	13.7	30.1	6.7	806	156
8	1574 to 1582	67/33	0.81	0.369	0.002	5.29	0.5	117	4.4	37.6	3.0	560	73.8
9	1588 to 1600	67/33	0.81	0.388	0.010	3.85	1.03	101	7.6	32.5	3.1	770	153
10	1606 to 1615	See table 21	0.81	0.367	0.001	5.84	0.66	109	6.7	37.5	2.7	864	101
11	1620 to 1629	See table 21	0.81	0.356	0.012	6.19	0.5	122	8.9	35.0	2.2	956	117

*Measured at one hour after IPDI addition

** Aged fuel premix

TABLE 7. LABORATORY SENSITIVITY DATA FOR UTP-18,803A PROPELLANT

T2408

Temperature, °F	State	Impact Sensitivity (OM-2 kg wt), kg cm	Friction Sensitivity (ESSO Screw)	Spark Sensitivity	Autoignition Temperature, °F
73	Cured	35	Ignites with glass grit	Negative at 9.0 joules	850 (30 sec) >850 (10 sec)
45	Cured	28		Negative at 9.0 joules	
73	Uncured	52	No ignition with diamond grit	Negative at 9.0 joules	

3.2 UTL-0040A LINER

The propellant interface system used for the ELSH and CHAR grains consisted of the UTP-18,803A propellant, UTL-0040A HTPB liner, and ORCO-9250 silica-asbestos insulation. Matters of importance to the integrity of this system, including the liner formulation, liner bond strengths obtained, moisture control during motor processing, and plasticizer migration effects, are discussed in this section.

3.2.1 Liner Description

CSD has standardized on the use of UTL-0040A liner in conjunction with HTPB propellant systems. The formulation of UTL-0040A is shown in table 8. Rheological properties are shown in figure 8. Studies have shown that UTL-0040A can be applied in 20- to 30-mil thickness without slump at 140°F. For best peel strength, the liner should not be fully cured before propellant is cast. A nominal precure of 16 hr at 140°F was used. However, in the event of an unexpected processing delay, a liner which has been precured can be held for at least an additional 72 hr at 120°F without detrimental effect on propellant/liner/insulation bond strength.

TABLE 8. FORMULATION AND PROPERTIES OF UTL-0040A LINER

T2407

Formulation	
R-45M HTPB	41.8% (1.0 equivalent)
DDI	12.2% (1.2 equivalent)
HX-868	6.0%
AO 2246	0.5%
Carbon black	39.5%
Properties	
Density	0.425 $lb/in.^3$
Thermal conductivity	2.27×10^{-6} Btu/in. sec°F
Ultimate strain (70°F)	160 to 340%

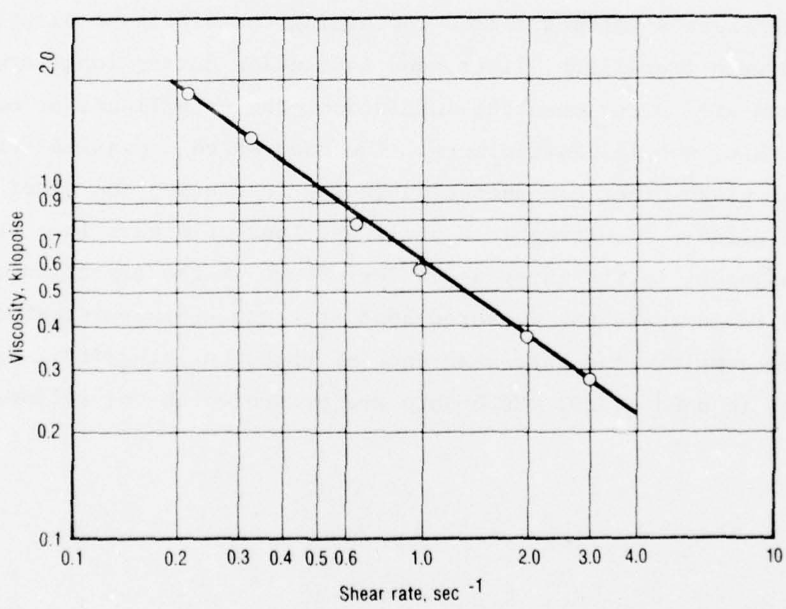

Figure 8. Rheology of UTL-0040A Liner

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3.2.2 Physical Properties

Extensive testing of the UTP-18,803A/UTL-0040A system under contract No. F04611-76-C-0010 (30 peel sets and 180 BITs) has demonstrated the adequate propellant/liner/cartridge adhesion characteristics. Furthermore, the 1/5-scale analog motor testing (section 4.1.2.2.3) and the extensive SEC testing (section 4.2.1.3) verified the satisfactory performance of the UTL-0040A liner over a temperature range far in excess of that specified for the 84-in. cartridges.

3.2.3 Migration Effects

Migration of moisture from the insulation into the liner and propellant can interfere with propellant bonding if adequate controls are not established. Studies at CSD have demonstrated that, if the ORCO-9250 rubber is dried for 5 days at 215°F before lining, no loss of bond strength occurs with an IPDI cured propellant and UTL-0040A liner. Therefore, a pre-dry of the insulation was established as a motor processing requirement for all of the ELSH and CHAR insulated cartridges processed under this effort.

Questions are sometimes raised concerning the effect of plasticizer migration between propellant, liner, and insulation during long-term aging. Such migration will occur when the insulation, the propellant, or both contain mutually soluble, mobile plasticizers. The case which prevailed here was for the effective plasticizer concentration in tne insulation and liner to be less than the propellant, resulting in a small net loss of plasticizer from the propellant adjacent to the interface. The effect of the migration in this instance was to increase the measured bond strength. Since interfacial phenomena are complex, the best assurance of bondline integrity is satisfactory bond strength in bond tests. Such data are presented in the following sections.

4.0 WORK ACCOMPLISHED

The work completed under contract No. F04611-76-C-0010, "84-Inch Propellant Cartridges and Grains," is described in this section by phase. The results of the grain analyses, propellant characterization (both physical and ballistic), and the method of propellant processing are summarized in appropriate subsections. Details of these summaries are provided in volumes II and III of this report to permit closer examination of the data as desired.

4.1 PHASE I - DESIGN REQUIREMENTS, ELSH

The phase I effort encompassed (1) establishing the propellant grain design criteria as specified in the contract SOW and the Prime Item Development Specification for ELSH, (2) development of a propellant which met all design criteria from both physical property and ballistic aspects, (3) establishment of a grain design, and (4) analysis of the grain design to verify its compatibility with the contract requirements. Each of these aspects is discussed below.

4.1.1 Design Criteria

The design criteria established for the ELSH propellant grains as defined by the contract prime item specification (appendix A) are summarized in table 9.

4.1.1.1 Propellant Selection

The propellant specified for use in the casting of the 20 ELSH cartridges was CSD's UTP-18,803A, a 90% solids, 21% aluminum, HTPB (R-45M) propellant which had already been transitioned to the 400-gal production mixer before initiating this effort. As discussed further in section 4.1.2, a series of nine 5-gal mixes and one 400-gal preproduction mix was made to reverify the propellant ballistic and mechanical property characteristics with the specific chemical lots used for this effort before committing to production.

4.1.1.2 Motor Ballistics

The motor ballistic requirements are summarized in table 9. The typical motor test configuration is shown in figure 9.

TABLE 9. ELSH PROPELLANT GRAIN DESIGN CRITERIA

Propellant

UTP-18,803A

HTPB
90% solids
21% aluminum

Motor Ballistics

Use the existing ELSH motor grain configurations as defined by:

P/N C11479-01-01 (2/motor required)
P/N C11479-02-01 (1/motor required)
P/N C11479-03-01 (1/motor required)

Nominal ballistics:

$\overline{P}_c$ = 1,400 psi ± 5%

D_{t_i} = 14.67 in.

$\dot{D}_t$ = 6.35 mils/sec

MEOP = 1,700 psi at 70°F

t_b = 60 sec

Cartridge Design

GFE item per drawing P/N C10279 (uninsulated)

Insulation System Design

Designed for the following conditions:

1. Minimum safety factor of 2.0 on CHAR penetration, or
2. Minimum safety factor of 2.0 on minimum interface temperature, whichever is critical

4.1.1.3 Propellant Physical Properties

The prime item development specification for ELSH stipulated the following general physical criteria to be met by UTP-18,803A:

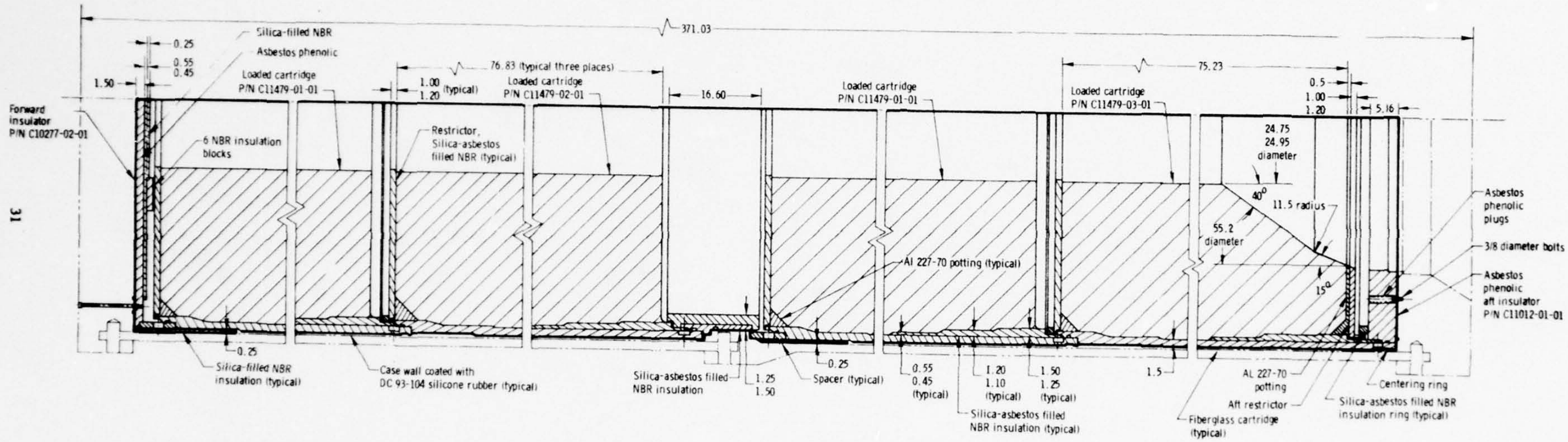

Figure 9. ELSH Motor
Configuration

07295R

Description	Criterion	Conformance
Service life	24 months	Testing of subscale analog motors after 2-year aging
Environmental conditions		
Storage temperature	60° to 80°F	Analog motor testing
Operating temperature	60° to 80°F	
Humidity	≤50%	
Transportation/handling	Vibration, shock, and acceleration normally experienced during shipment by truck or railway for a temperature range of -20° to 135°F	
Bondline strength	Propellant/cartridge bondline to exceed cohesive strength of propellant	Propellant specification, demonstrated in analog motor tests
Factors of safety		
Propellant	1.5	Factors of safety applied in analysis for calculating margins of safety
Bondline	2.0	

4.1.2 Propellant Characterization (Preproduction)

Before committing to production of UTP-18,803A for casting in the ELSH and CHAR grains, a series of nine 5-gal batches and one full-scale, 400-gal batch was made to optimize the propellant's mechanical and ballistic properties for the particular chemical lots used for the production phase.

4.1.2.1 Five-Gallon Optimization

The objective of the 5-gal work was to optimize the propellant in terms of burning rate and physical properties for use in the ELSH and CHAR loaded cartridges. The matrix investigated is identified below by batch number.

	AP Grind Ratio (Unground/Ground)		
NCO/OH	65/35	60/40	55/45
0.86	5-1711	5-1712	5-1713
0.83	5-1714	5-1715	5-1716
0.80	5-1717	5-1718	5-1719

Each batch was subjected to both ballistic and mechanical property evaluations.

4.1.2.1.1 Ballistic Properties

The ballistic evaluation consisted of testing three 2C micromotors and three 4-lb motors from each batch. The motor descriptions are presented in table 10. As can be seen from the small size of the micromotor, its primary purpose is that of providing a means of quickly screening propellant ballistic performance at minimal cost. It is a very useful tool in establishing the general ballistic characteristics. The 4-lb motor uses a large enough propellant load while providing sufficient burning duration and neutrality to allow accurate data reduction.

The ballistic evaluation of each of the 5-gal batches consisted of testing three micromotors and three 4-lb motors. One of each type motor from each batch was designed for testing at 800, 1,000, and 1,400 psi to cover the range of nominal ballistics required by the ELSH and 84-in. CHAR grains to be

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TABLE 10. BALLISTIC MOTOR DESCRIPTION

	Micromotor	4-lb Motor
Wp, lb	0.07	4.0
OD, in.	1.13	4.51
ID, in.	0.73	3.30
Length, in.	2.00	8.40
Web, in.	0.20	0.60
$\bar{A}_b$, in.^{2}	5.7	102.0
$\Delta\bar{A}_b$, %	+1.3	+0.75
Maximum P_c, psi	10,000	4,000
Maximum thrust, lb	None	15,000

cast under this program. The ballistic data from the micromotors and the 4-lb motors are presented in tables 11 and 12, respectively. Volume II of this document presents a compilation of the raw test data.

4.1.2.1.2 Mechanical Properties

Each 5-gal batch was subjected to a series of tests to determine stress, strain, elongation, and initial modulus. Testing was conducted at a crosshead

TABLE 11. MICROMOTOR BALLISTIC DATA, 5-GAL MATRIX

Batch	Grind Ratio	NCO/OH	r_{1000}, in./sec	r_{1400}, in./sec	Exponent, n	Burning Rate Constant, a	One-Sigma, %
5-1711	65/35	0.86	0.445	0.508	0.397	0.0287	2.4
5-1712	60/40	0.86	0.482	0.593	0.615	0.00688	2.1
5-1713	55/45	0.86	0.522	0.686	0.814	0.00189	3.1
5-1714	65/35	0.83	0.484	0.586	0.573	0.00926	2 pt tested
5-1715	60/40	0.83	0.467	0.580	0.641	0.00560	4.61
5-1716	55/45	0.83	0.499	0.723	1.11	0.00024	9.4
5-1717	65/35	0.80	0.442	0.5096	0.423	0.02385	2 pt tested
5-1718	60/40	0.80	0.477	0.573	0.543	0.01123	0.3
5-1719	55/45	0.80	0.531	0.772	1.106	0.00026	2 pt tested

TABLE 12. 4-LB MOTOR BALLISTIC DATA 5-GAL MATRIX

Batch	Grind Ratio	NCO/OH	r_{1000}, in./sec	r_{1400}, in./sec	Exponent, n	Burning Rate Constant, a	One-Sigma, %	LSBR EOM 1400
5-1711	65/35	0.86	0.415	0.487	0.472	0.01591	1.8	0.587
5-1712	60/40	0.86	0.439	0.538	0.603	0.00682	1.8	
5-1713	55/45	0.86	0.489	0.594	0.583	0.00867	2 pt	
5-1714	65/35	0.83	0.411	0.490	0.522	0.01116	2.2	0.582
5-1715	60/40	0.83	0.442	0.530	0.543	0.01038	1.2	
5-1716	55/45	0.83	0.482	0.577	0.534	0.01209	2 pt	
5-1717	65/35	0.80	0.413	0.496	0.547	0.00943	3.2	0.593
5-1718	60/40	0.80	0.457	0.554	0.573	0.00872	3.6	
5-1719	55/45	0.80	0.473	0.581	0.610	0.00700	2 pt	

rate of 2 in./in./min at -20°, 72°, and 135°F. In addition, the batches made with an AP grind ratio of 60/40 were also subjected to high rate pressurization tests (90 in./in./min at 1,000 psi) at 72°F. The data are summarized in table 13. For ease of comparison, figure 10 presents a comparison of the low-rate (2 in./in./min) and high-rate (90 in./in./min) test data.

Evaluation of the mechanical and ballistic data indicated that the 65/35 grind ratio would yield the ballistic properties required for the ELSH/CHAR motors while a curative ratio in the 0.83 to 0.86 range provided the best physical properties. Therefore, CSD selected an AP grind ratio of 65/35 and an equivalence ratio of 0.85 for use in the full-scale preproduction mix.

4.1.2.2 400-Gallon Preproduction Batch

The 400-gal preproduction batch, identified as CSD batch No. 400-1450, was made using a curative ratio of 0.85 and an AP grind ratio of 65/35. The purpose of the 400-gal mix was to evaluate UTP-18,803A using the production mixer before committing to production of the ELSH/CHAR grains. The propellant was subjected to a series of tests to characterize and identify any mixer scale effects on the ballistic and mechanical properties. The tests conducted on batch 400-1450 are summarized in table 14 and the results are discussed below.

4.1.2.2.1 Ballistic Properties

The ballistic properties were evaluated through a series of tests ranging from LSBR up through 4-lb motor, 15-lb BATES, and 70-lb BATES. These tests were performed to: (1) establish the nominal propellant ballistics (4-lb motors tested at ambient conditions); (2) establish the effect of motor size on burning rate (4-lb vs 15-lb BATES vs 70-lb BATES); and (3) determine the temperature sensitivity of UTP-18,803A (4-lb motors at 32°, 85°, and 128°F).

A. Nominal Propellant Ballistics (Mixer Scaleup Effect)

Seven 4-lb motors were fired at ambient conditions (85°F) to establish the burning rate characteristics of UTP-18,803A from the 400-gal

TABLE 13. MECHANICAL PROPERTY EVALUATION, 5-GAL MATRIX

		135°F				72°F				-20°F			
Batch	Test Speed	σ_m^c, psi	ε_m^c, %	ε_r, %	E_o, psi	σ_m^c, psi	ε_m^c, %	ε_r, %	E_o, psi	σ_m^c, psi	ε_m^c, %	ε_r, %	E_o, psi
1711	2 in./in./min	112	32	32	382	129	30	32	650	297	36	39	3,781
1712	2 in./in./min	119	31	31	430	144	29	30	692	296	35	39	3,115
1713	2 in./in./min	122	27	27	396	157	25	26	707	314	36	39	2,905
1714	2 in./in./min	93	31	31	302	112	29	31	539	242	43	48	2,675
1715	2 in./in./min	94	32	33	358	114	30	30	459	246	40	43	2,471
1716	2 in./in./min	66	31	33	223	89	30	31	347	203	32	47	2,053
1717	2 in./in./min	48	35	40	167	60	32	35	251	166	12	42	2,850
1718	2 in./in./min	50	29	31	173	60	28	30	231	173	21	43	2,169
1719	2 in./in./min	50	29	31	174	66	28	33	249	178	17	35	2,093
	High rate pressurized												
1712	Strain rate 90 in./in./min at 1,000 psig	-	-	-	-	908.6	47.1	50.3	3,489	-	-	-	-
1715	Strain rate 90 in./in./min at 1,000 psig	-	-	-	-	672	50.9	55.0	2,319	-	-	-	-
1718	Strain rate 90 in./in./min at 1,000 psig	-	-	-	-	573.5	66.3	71.0	924	-	-	-	-

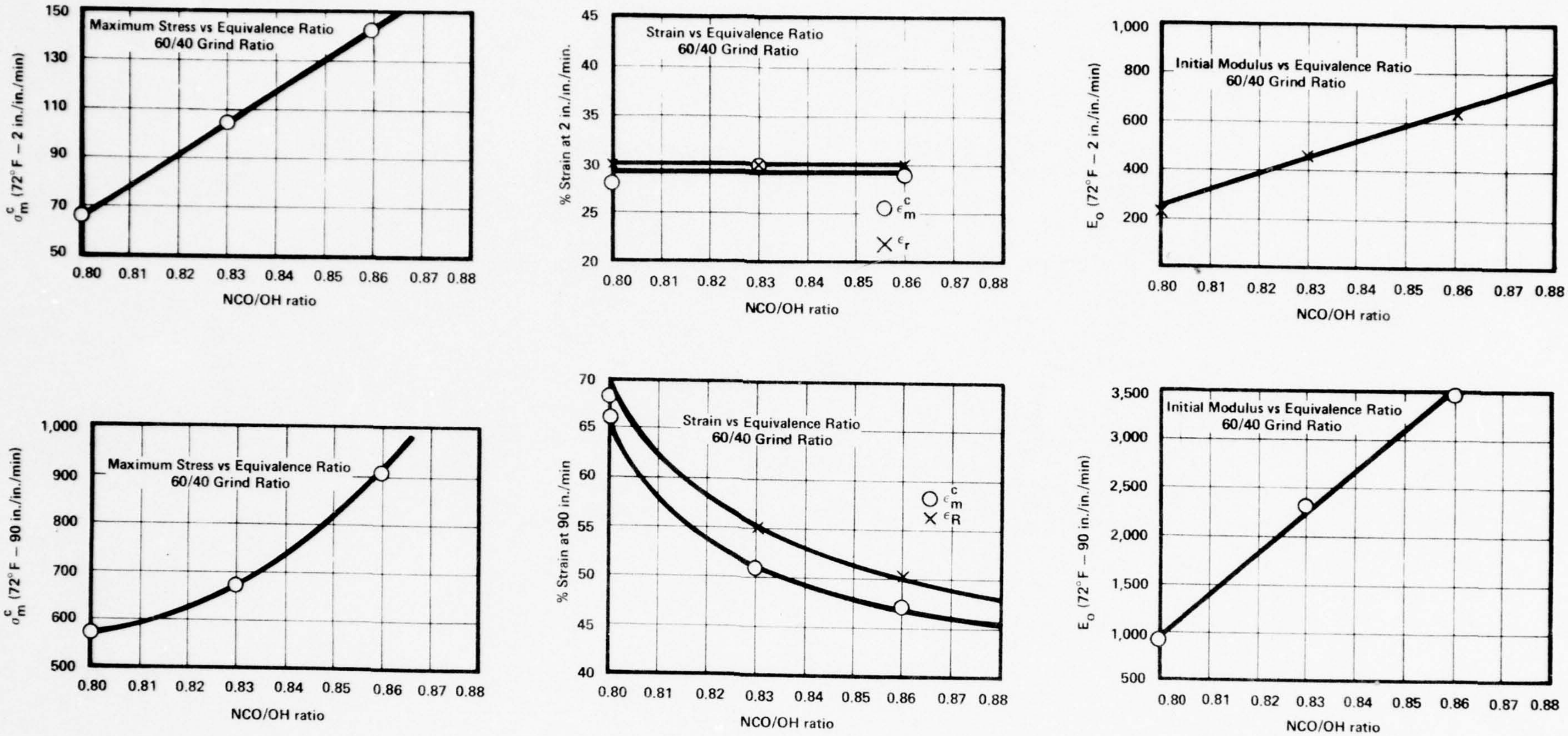

Figure 10. Low-Rate and High-Rate Test Data Comparison

TABLE 14. 400-GALLON PREPRODUCTION TESTS, BATCH 400-1450

Item Cast	Sample	Property Measured	Method/Specimen	Test Matrix	Purpose of Test
Propellant samples	1/2-gal carton	Ingredient verification	% aluminum % total solids	N/A	Verify that proven formulation is being made
	3/8-in. straw	Burning rate, precurative	LSBR	P = 1,000 psi, 1,400 psi T = ambient	Ensure ballistic behavior is as required before addition of curative; verify agreement with propellant specification requirements
	3/8-in. straw	Burning rate, end-of-mix	LSBR	P = 1,000 psi; 1,400 psi T = ambient	Ensure proper ballistics before committing to motor casting; verify agreement with propellant specification requirements
	1/2-gal carton	Mix viscosity	Haake	1 hr after end of mix	Verify pot life of propellant
Test specimens - mechanical property	1/2-gal carton	Uniaxial properties	Maximum corrected stress; maximum corrected strain; true strain at rupture; initial tangent modulus	Standard JANNAF Class B at 75°F	Verify that propellant mechanical properties conform to propellant specification requirements
	Propellant/liner/ insulation	Propellant/liner/insulation bond	Bond-in-tension	Ambient conditions	Verify adequacy of propellant/ liner/insulation interface
	Propellant/liner/ cartridge	Propellant/liner/cartridge bond	Bond-in-tension	Ambient conditions	Verify adequacy of propellant/ liner/cartridge interface
Test specimens - ballistic property	4-lb motors	Burning rate	4-lb motor	P = 800, 1,000, 1,500, 2,000 psi T = ambient	Establish propellant burning rate; provide data for motor scaleup
Test specimens - ballistic property		Burning rate	4-lb motor	P = 800, 1,000, 1,500, 2,000 psi T = 32°F, 85°F, 128°F	Establish π_K and σ_p for UTP-18,803A
	15-lb BATES	Burning rate	15-lb BATES (AFRPL)	P = 1,000, 1,400 psi T = ambient	Propellant burning rate; provide motor burning rate scaleup data
	70-lb BATES	Burning rate	70-lb BATES (AFRPL)	P = 1,000 psi T = ambient	Propellant burning rate; provide motor burning rate scaleup data
Subscale analog motors	1/5 subscale ELSH	Grain/cartridge integrity	Temperature cycling of motors	Cycle four motors from -20°F to 135°F three times; cycle two motors to -60°F to induce failure; age two motors for two years and cycle to -60°F to induce failure	Demonstrate structural adequacy of grain/cartridge

preproduction batch. The results are shown in figure 11. The burning rate equation for the propellant is

$$R = 0.0123P_c^{.51}$$

This compares to the burning rate equations from the comparable 5-gal mixes (65/35 grind ratio) of:

$$R_{5-1711} = 0.01591P_c^{.47}$$

$$R_{5-1714} = 0.01116P_c^{.52}$$

$$R_{5-1717} = 0.0094P_c^{.55}$$

While some variation does exist due to the limited sample sizes used to establish these equations, analysis of the calculated burning rates from these equations demonstrates that they must be considered to be of the

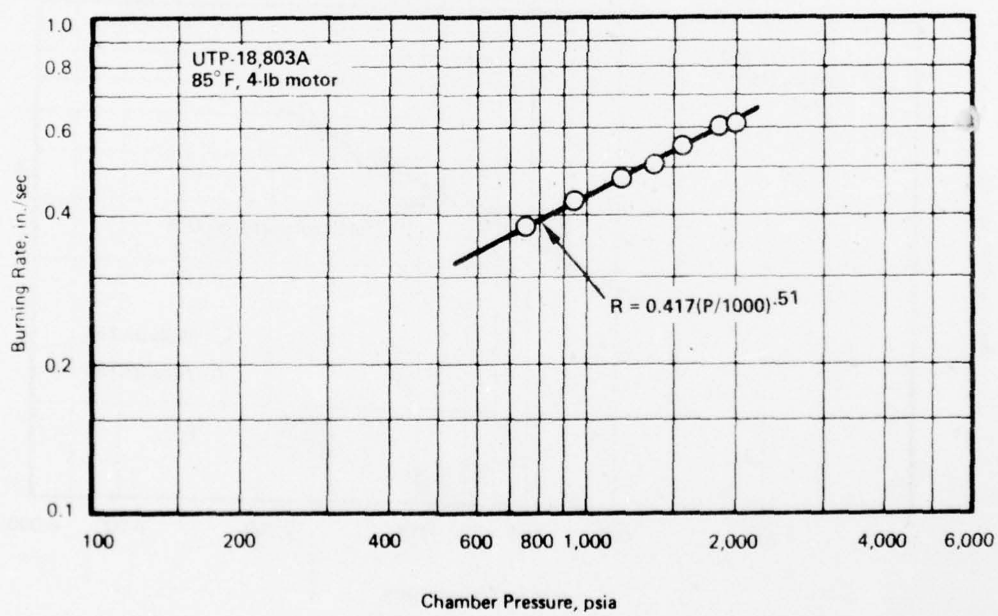

Figure 11. Nominal Propellant Ballistics, Batch 400-1450

same population and that mixer scaleup effects from the 5-gal to the 400-gal size are not significant for UTP-18,803A.

B. Motor Size Burning Rate Scaleup

To determine the effect of motor size on propellant burning rate, six 15-lb BATES and three 70-lb BATES motors were cast from batch 400-1450 and tested at AFRPL. All BATES tests were fired at a nominal 70°F. Of the nine motors tested, three 15-lb and two 70-lb motors were fired at a nominal 850 psi; three 15-lb motors and one 70-lb motor were tested at a nominal 1,350 psi. The data are plotted in figure 12. As shown, UTP-18,803A exhibited no significant motor size burning rate effect. This was further verified in the testing of UTP-18,803A from the subsequent production runs in which analyses of burning rate data from

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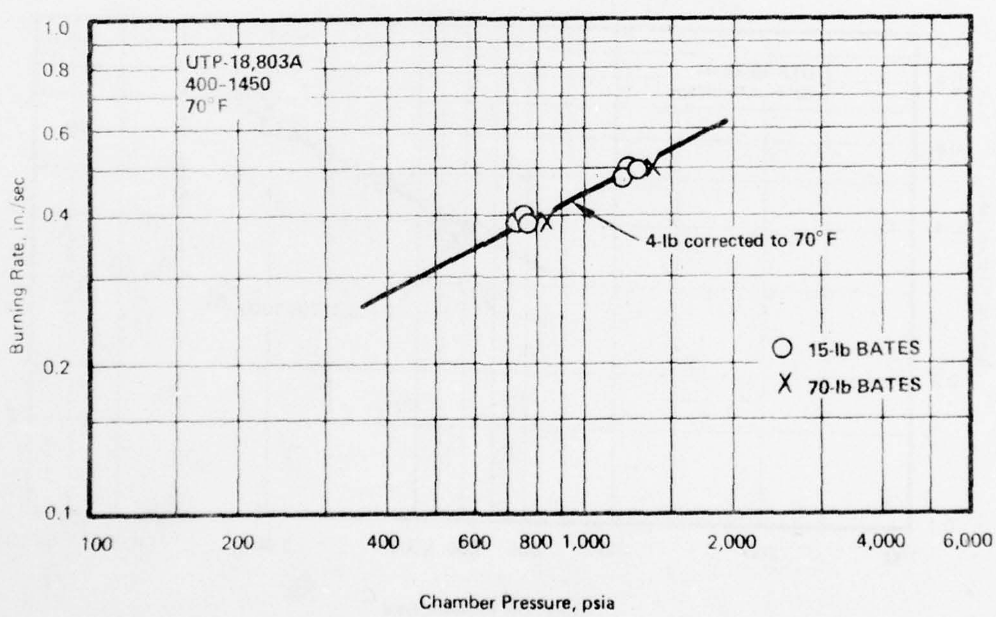

Figure 12. Motor Burning Rate Scaleup Data, 400-gal Preproduction Batch

4-lb motors, 15-lb BATES, 70-lb BATES, and 84-in. CHAR motors showed virtually the same burning rate independent of motor size (section 4.2.5.1).

Figure 13 presents a comparison of the calculated K_n for the 15-lb and 70-lb BATES motors with the 4-lb motor values. As was the case with the burning rates, the K_n values compared quite favorably for each of the three motor sizes.

C. Propellant Temperature Sensitivity

Sixteen 4-lb motors were tested to establish the burning rate temperature sensitivity of UTP-18,803A. The testing, which was conducted at propellant temperatures of 32°, 85°, and 128°F, is summarized in table 15 and illustrated in figure 5. The calculated temperature sensitivity for UTP-18,803A is: $\pi_K = 0.104\%/°F$ and $\sigma_p = 0.0498\%/°F$, which is calculated from the relationship $\sigma_p = \pi_K (1-n)$.

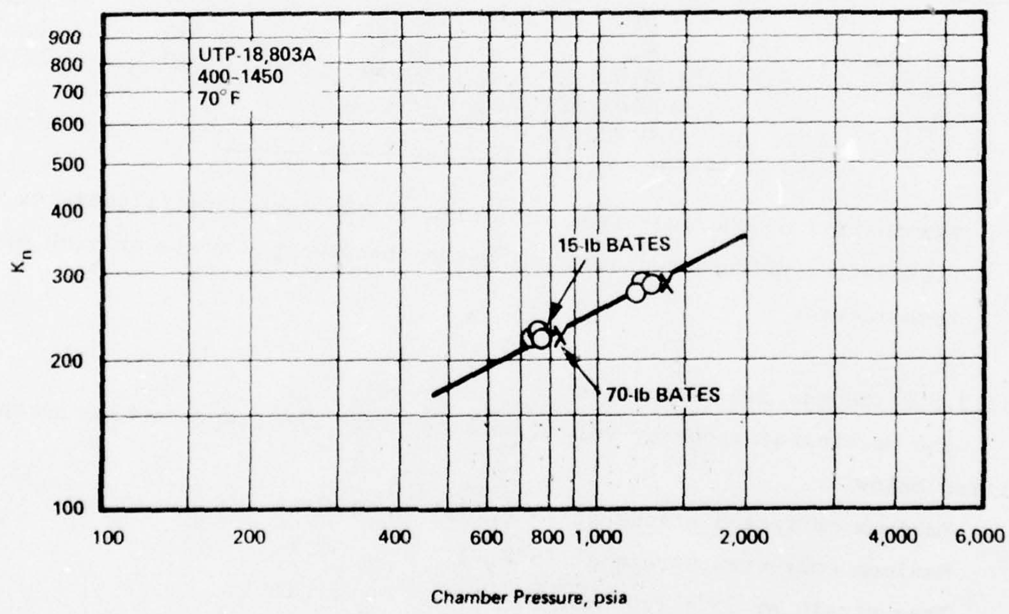

Figure 13. K_n as a Function of Pressure and Motor Size

TABLE 15. TEST POINTS, UTP-18,803A TEMPERATURE SENSITIVITY

Temperature, °F	Chamber Pressure, psia	Burning Rate, in./sec
32	2,165	0.6104
32	1,580	0.5339
32	1,276	0.4562
32	1,012	0.4110
32	789	0.3649
128	947	0.4148
128	1,299	0.4923
128	1,655	0.5675
128	1,989	0.6219
85	2,043	0.5950
85	1,895	0.5837
85	1,437	0.4906
85	1,238	0.4630
85	1,004	0.4177
85	802	0.3735
85	1,595	0.5358

Temperature, °F	Composite r_{1000}, in./sec	r_{1400}, in./sec	Pressure Exponent	One-Sigma, %
32	0.410	0.489	0.522	1.70
128	0.427	0.514	0.550	0.44
85	0.416	0.494	0.510	1.19
π_K	0.104%/°F			
σ_p	0.0498%/°F			

Examination of the one-sigma variation of the test data illustrates the high degree of reproducibility obtained between the tests at each given temperature.

4.1.2.2.2 Mechanical Properties

The mechanical property values obtained from the preproduction batch are listed below.

Maximum corrected stress at 75°F, psi	120.1
Maximum corrected strain at 75°F, %	30.7
True strain at 75°F rupture, %	31.6
Initial tangent modulus	1,229

4.1.2.2.3 Analog Motor

The contract required that a series of four subscale analog motors be fabricated with UTP-18,803A and temperature cycled from -20°F to 135°F for three cycles. A period of 24 hr was given to reduce the temperature from 135° to -20°F. Following these tests, two motors were to be aged for 2 years and the cycling repeated. The remaining two motors were to be subjected to an overtest in which they would be cycled from 135° to -60°F three times. This section describes the construction of the analog motors, the testing completed, and the test results obtained.

The program consisted of the manufacture and testing of four motors. These motors, illustrated in figures 14 through 16, were 1/5-scale geometric models of the full-size ELSH cartridges. They were made of the same materials as the full-size cartridges and included the rubber insulation and rubber inhibitor. The analog motors were fabricated by the vendor who fabricated

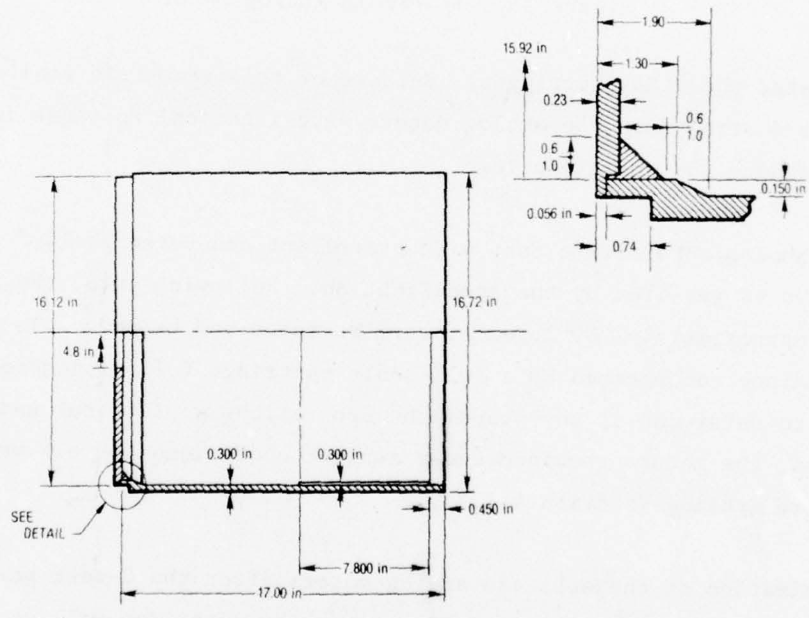

Figure 14. Subscale Analog Motor Cartridge

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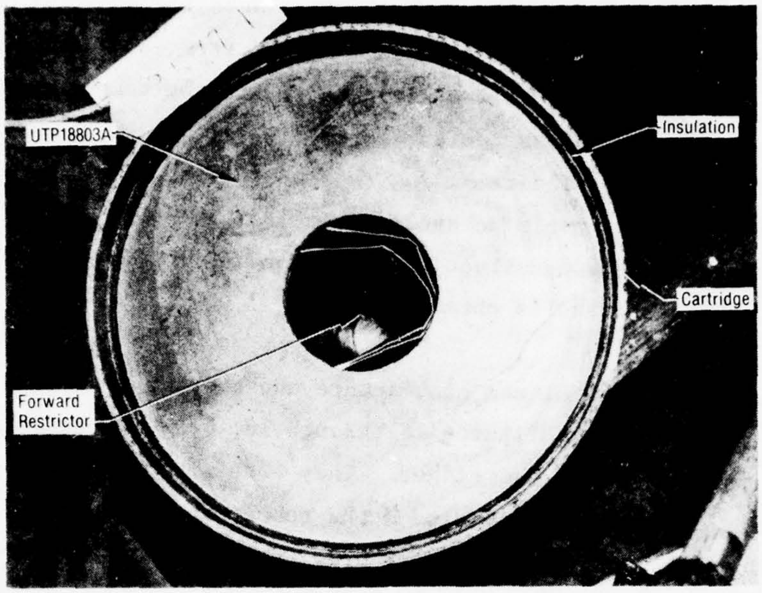

Figure 15. 1/5-Scale Analog Motor

and insulated the ELSH cartridges. Because of this geometric scaling, the stresses and strains in the analog motors were identical to those in the full-size cartridges for any given load.

The analog motors were cast with propellant and cured at 140° ± 10°F for 10 days as required by the specification. Following cure, the motors, weighing approximately 200 lb each, were stripped and trimmed. To simulate the conditions encountered by a full-scale cartridge following normal propellant cure and to determine if any propellant separations would occur under these conditions, the motors remained under ambient conditions for two weeks before temperature cycling (section 4.1.3).

Examination of the subscale analog motors after the 2-week period showed minor separations within the propellant near the cartridge wall at the aft end, which accurately simulated the separations that subsequently occurred in the full-scale cartridges. These separations (figure 17) were left as-is during the

Figure 16. Subscale Analog Motors

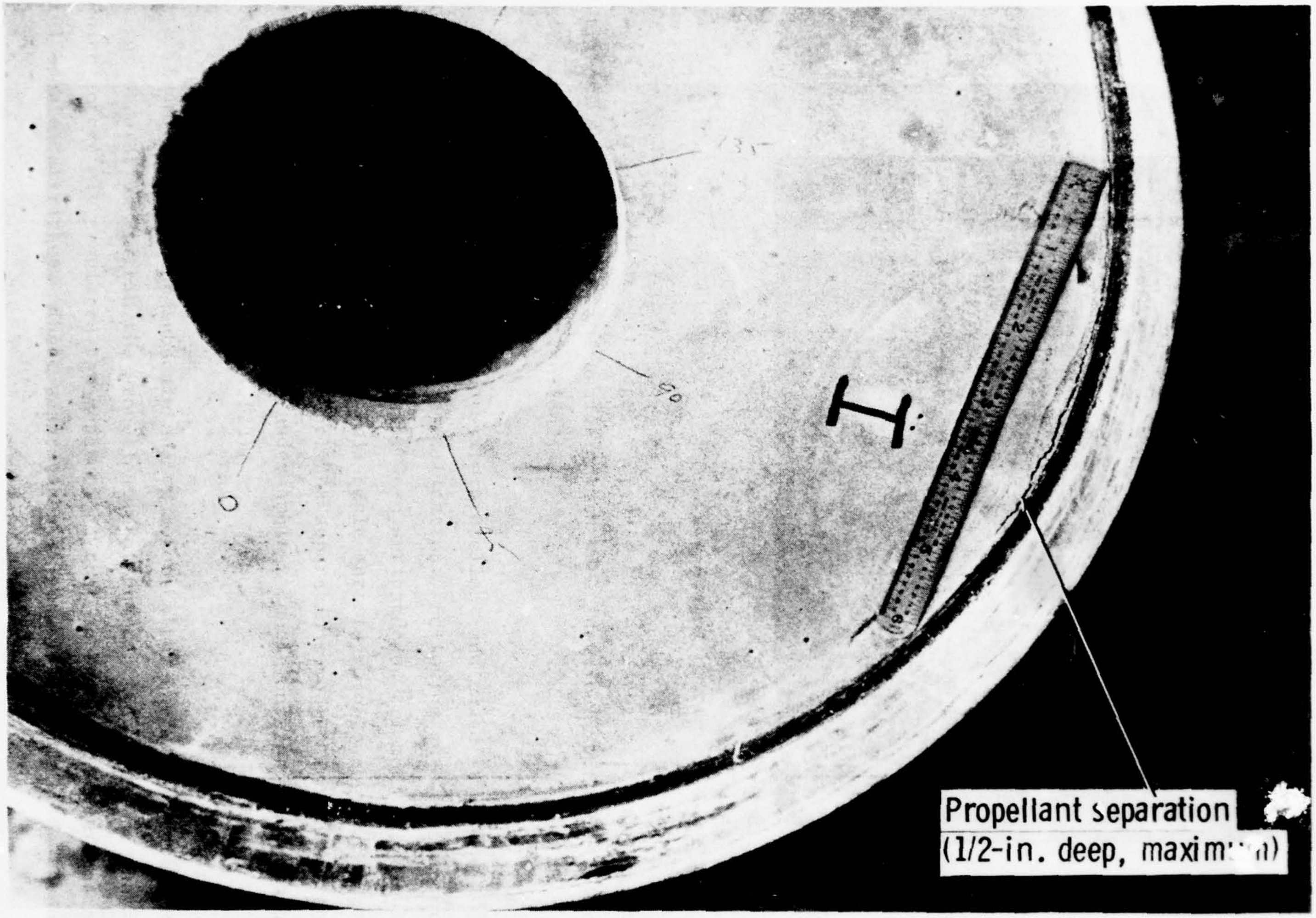

Figure 17. Propellant Separations, Analog Motors

subsequent testing to determine if they had stabilized or would progress further due to the temperature cycling. Each of the four analog motors were subjected to thermal cycling between -20° and 135°F and back to -20°F for these cycles. The time to go from -20° to 135°F was 24 hr. The temperature cycle used for these tests is shown in figure 18.

Following completion of the thermal testing, the analog motors were examined visually and with x-rays. No propellant/cartridge or propellant/insulation separations were noted other than the minor separations described above. These separations, which went to a maximum depth of 1/2 in., appeared to have stabilized and did not progress further due to the temperature cycling.

Two of the analog motors were then subjected to thermal cycling from -60° to 135°F in an overtest designed to induce grain failure. No failures were noted.

The remaining two analog motors were artifically aged for an equivalent of 2 years and subjected to the same -60° to 135°F cycle three times to induce grain failure. No failure was noted.

These tests demonstrated the adequacy of the propellant and grain design for ELSH. The adequacy of the simulation of the ELSH stress/strain field by the analog motors was demonstrated by the accurate modeling of the ELSH aft face separation by the analogs. The adequacy of the propellant/grain design was demonstrated as the analog motors withstood failure during severe overtest conditions which would not be encountered by an 84-in. loaded cartridge.

4.1.3 Grain Design

The ELSH grain configurations were specified in the contract in terms of propellant type and ballistic requirements. The propellant was specified as a 90% solids HTPB formulation containing 21% aluminum. The specified ballistics included: an average chamber pressure of 1,400 psia and an initial throat diameter of 14.675 in. with a 6.35 throat erosion rate. These optimum conditions determine the required propellant ballistic and physical properties

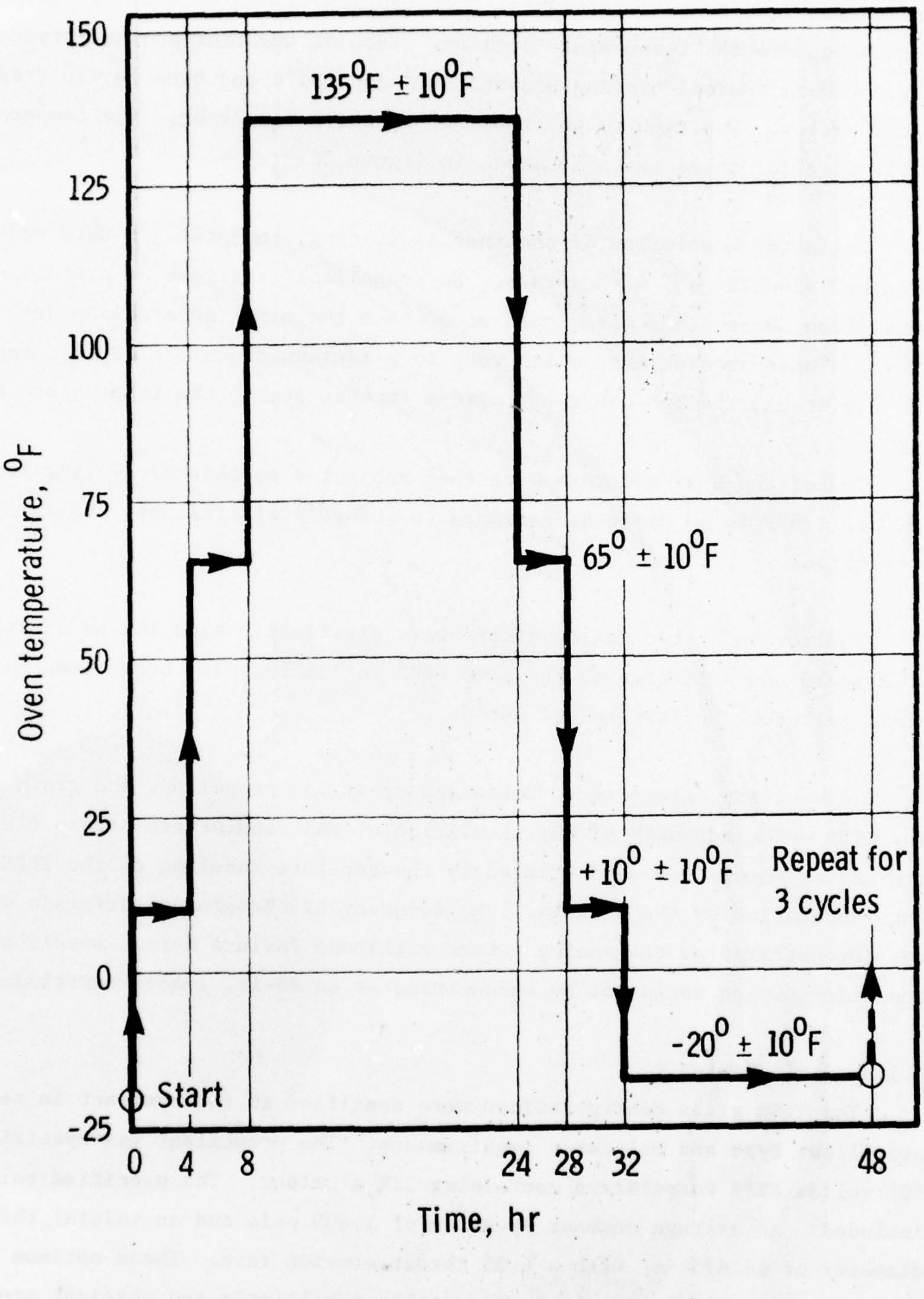

Figure 18. Thermal Cycle, ELSH Analog Motors

summarized in table 16. The delivered characteristic velocity is corrected for the heat loss to the exposed surface areas of the ELSH combustion chamber.

Figure 9 shows the assembled ELSH grain configuration specified in the contract. The propellant grain for the ELSH consists of four cartridge-loaded segments: three identical segments and an aft segment containing a cavity to accommodate a submerged nozzle and provide local flow conditions representative of an MX lower-stage nozzle. The three-forward-segment grain geometry is a fully case-bonded simple internal cylindrical bore design, 76.83-in. long with a 24.85-in. bore diameter. The forward face of the aft segment is restricted to improve neutrality. The aft face is also restricted to provide the desired flow conditions around the nozzle.

Though the web fraction is moderately high (70% or B/A - 3.24), the short L/D (0.95) of the segments and the simple circular internal perforation contribute to a reliable low stress grain design; therefore, the propellant stress relief flaps (or boots) at the ends of the grain, determined as not cost effective, were eliminated. Accordingly, it was recognized that minor separations could develop at the ends which would be subsequently potted before usage. (These separations did occur, were accurately modeled by the analog

TABLE 16. BALLISTIC AND PHYSICAL PROPERTIES REQUIRED FOR ELSH PROPELLANT

T0404

Ballistics	
Burning rate at 1,400 psia, in./sec	0.492
Solid density, lb/in.^{3}	0.0666
Flame temperature, °R	6,790
Theoretical characteristic velocity, ft/sec	5,188
Delivered characteristic velocity in ELSH accounting for heat losses, ft/sec	5,100
Physical properties	
True elongation at maximum load, %	20
Measured tensile strength at maximum load, psi	50
Uniaxial endurance strain at 1 yr, %	10
Bond system endurance stress at 1 yr, psi	20

motors, and did not compromise the grain performance since they were eliminated by potting them with AL-227).

A summary of the ELSH motor and grain characteristics is given in table 17. Figure 19 shows the propellant surface area as a function of time.

The MEOP for the motor was calculated by correcting the maximum 70°F pressure to 90°F and then adding a possible three-sigma variance of 4.08%. The variable estimate is based on 120-in. motor data where a variance on maximum pressure of 3.48 was observed for multiple batches of propellant having an exponent of 0.25. These data include motor hardware variations such as tolerances and nozzle erosion. For the ELSH propellant exponent, this predicted variance extrapolates to 4.08%.

Figure 20 presents the ELSH forward end and aft end stagnation chamber pressure versus time, as predicted by CSD's LF12ZZZ internal ballistics computer program. The program accepts the grain geometry and propellant and motor data as input, calculates the surface area history, then switches to an internal ballistic mode so that a complete end-to-end analysis is obtained with one computer access. The program divides the motor into a finite number of sections, or modules. Each module performs according to its local conditions (Mach number, burning rate, and static pressure). Mach number and pressure-field calculations were determined from one-dimensional flow equations; however, the program has a two-dimensional capability for the case of slot flow and flow behind a submerged nozzle which was used for the ELSH analysis. The program also accounts for erosive burning effects by a modified version of the Lenoir-Robillard equation. The program simulates actual motor conditions in that nonequilibrium conditions are assumed for the mass flow in and out of the chamber. In this manner, a continuous rate of change of chamber pressure is determined, so that ignition transients and tailoff blowdown are automatically obtained.

TABLE 17. ELSH MOTOR AND GRAIN CHARACTERISTICS

T0403

Parameter	Value
Throat diameter, in.	14.675
Throat erosion rate, mil/sec	6.3
Port-to-throat ratio	2.86
Average chamber pressure, psia	1,400
MEOP at 70°F, psia	1,700
MEOP at 80°F, psia	1,729
Grain	
Length, in.	
Forward segments (C11479-01-01 and -02-01)	76.83
Aft segments (C11479-03-01)	75.23
Bore diameter, in.	24.85
Outside diameter, in.	80.56
Web thickness, in.	27.855
b/a ratio	3.24
Web fraction	.69
Grain volume, $in.^3$	
Forward segments	1.027×10^6
Aft segment	3.10×10^5
Total	1.337×10^6
Propellant weight, lb	
Forward segments (per segment)	22,807
Aft segment	20,667
Total	89,088

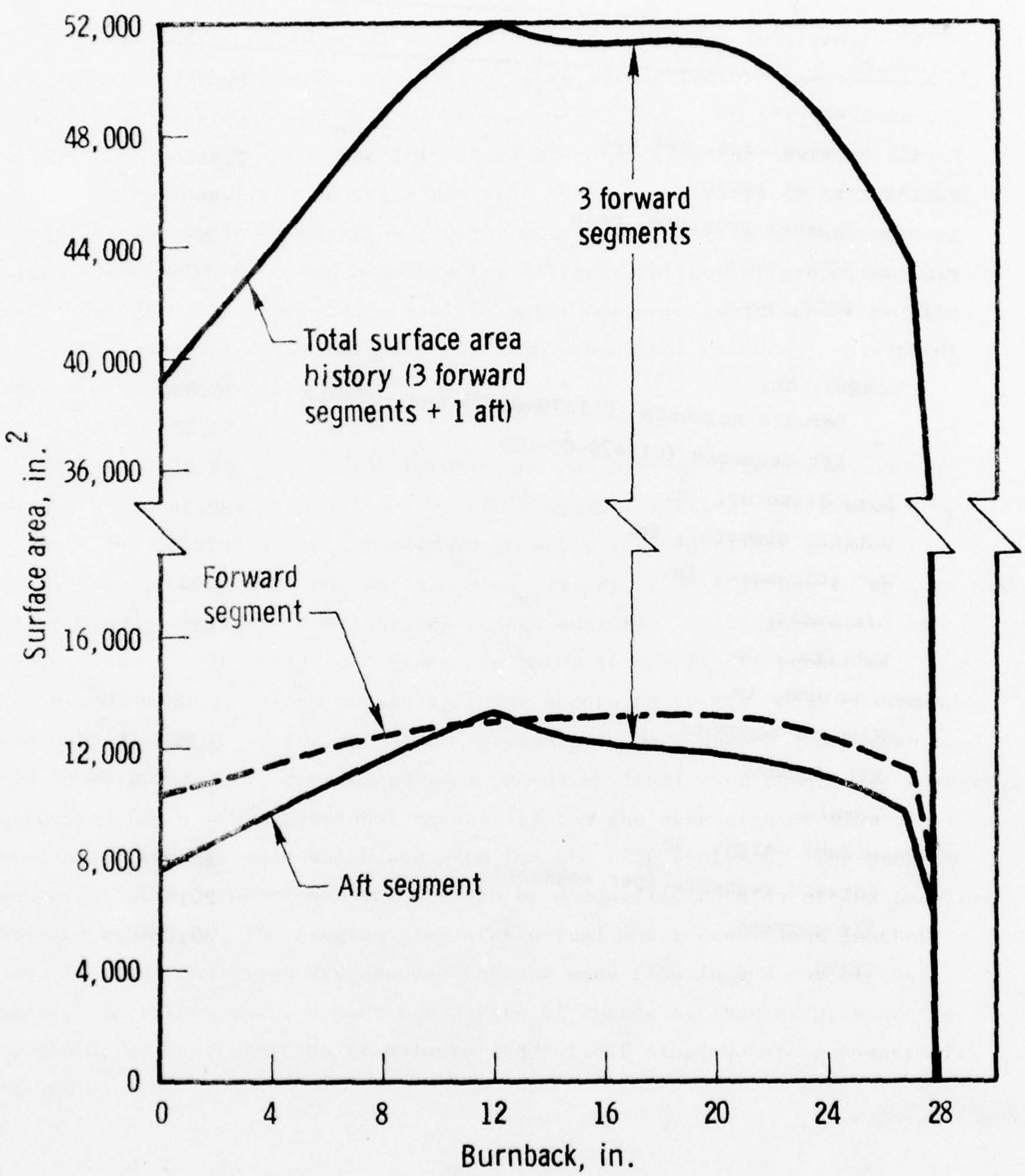

Figure 19. Segment and Motor Surface Area History

07294

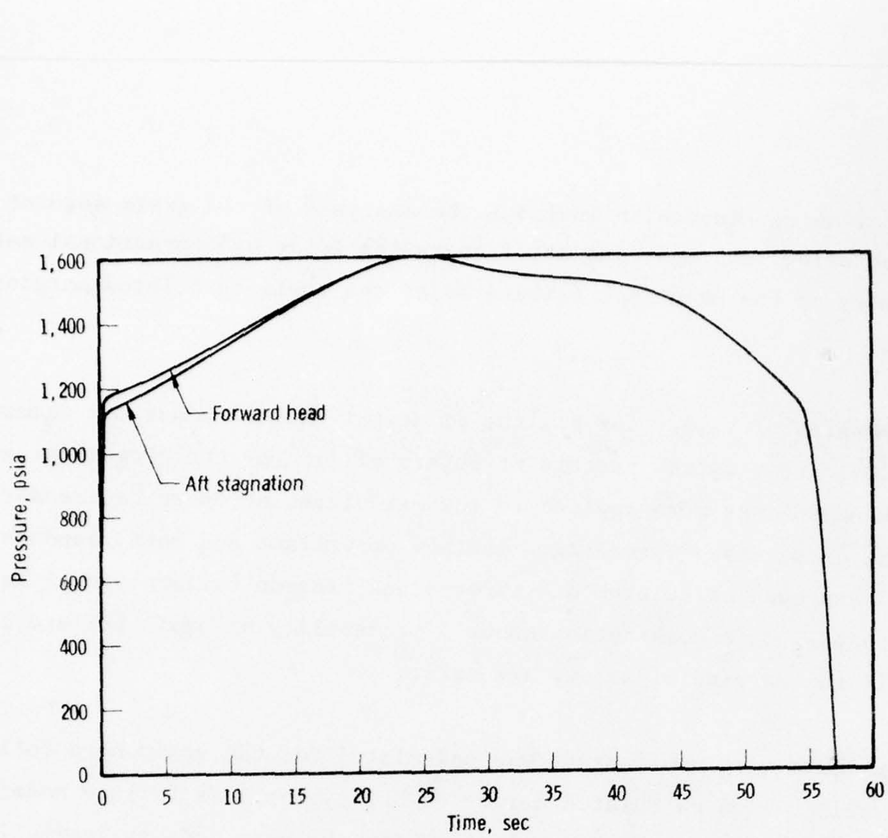

Figure 20. Chamber Pressure vs Time, 70°F

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4.1.4 Grain Design Analysis

From the structural viewpoint, the ELSH propellant grains may be characterized as cartridge-loaded cylindrical grains with a B/A of approximately 3.0 and an L/D of approximately 1.0. They have free ends with a rubber inhibitor on one end and no stress-relief boots at the bond terminations. As such, they could be analyzed with a conventional two-dimensional quasiviscoelastic analysis method. With the properties measured for UTP-18,803A, high margins of safety exist. The conventional two-dimensional quasiviscoelastic analysis included the use of an elastic finite element analysis in which the elastic properties used were derived from a viscoelastic characterization of the propellant. When necessary, nonlinear behavior was also taken into account in a simplified manner in this procedure. This analysis procedure has been used for all the 84-in. CHAR motor and Super HIPPO grains delivered by CSD to AFRPL and successfully fired to date.

The following discussion includes the analysis of the grain segment for manufacturing, storage, and motor operating loads by conventional methods and a summary of the principal failure modes and their associated margins of safety.

The margins of safety for all the principal failure modes are summarized in table 18. The required factors of safety of 1.5 for the propellant and 2.0 for the bondlines were applied to the calculated stresses before deriving the margins of safety. Three-sigma maximum propellant and bond responses to the loads have been calculated and three-sigma minimum failure properties have been used. This combination shows a probability of grain failure of 1 in 10^9 if the margins of safety are zero.

The minimum margin of safety was calculated for the grain bond following thermal cycling. The calculated margin of safety for this failure mode is +0.70. The margin of safety for a failure for the same mode following 2-year storage is +0.14. This margin is believed to be conservative (as demonstrated through the analog motor testing) because a nonlinear analysis would show much lower bore strain values at lower temperatures. This is demonstrated by measurements made on SECs of UTP-15,908, the C-4 HTPB 90% solids propellant, for which the thermal load response is shown in figure 21. The measured strain level shown in figure 21 is much lower than that predicted by linear analysis. This was further demonstrated for UTP-18,803A by testing of SECs from production batch 400-1539. Figures 22 and 23 show the results of cool-to-failure tests on UTP-18,803A SECs with B/A values ranging from 3.1 to 7.4. The SEC having the highest B/A failed at 40°F with 24% bore strain. No other failures occurred, although the remaining SECs were cooled to -85°F, with bore hoop strains exceeding 28% at this temperature. (The ELSH B/A is 3.24.)

Finite element analysis, extensively used for 10 years for propellant grain analysis, was used for this grain design. This is the well-known Rohm and Haas program for axisymmetric isotropic solids in an orthotropic case. Although a variety of programs are available at CSD (table 19), this program has been thoroughly evaluated for grain analysis and provides a high-quality,

TABLE 18. STRUCTURAL ANALYSIS OF SUPER HIPPO CARTRIDGE LOADED PROPELLANT (UTP-18,803A)

T0405

(1) Failure Mode	(2) Calculated (A) Stress/Strain, psi, %	(3) Minimum Specified Allowable Stress/Strain psi, %	(4) Reduced (B) Allowable for Variability and Aging Effects, psi, %	(5) Margin of Safety, (4)/(2) - 1
Failure modes due to storage for 2 yr between 60° and 80°F				
Unbond at grain termination due to combined shear and tension forces	14.7	20 (C)	16.7	0.14
Hoop strain failure in bore	4.1	8 (D)	6.7	0.63
Failure modes during transportation				
Unbond at grain termination from combined shear and tension forces due to cooldown to -20°F	29.4	60 (E)	50	0.70
Unbond at grain termination due to 2 g shock load	7.2	100 (F)	83	>10
Hoop strain failure in bore due to cooldown to -20°F	8.2	13 (E)	10.8	0.32
Unbond at grain termination due to cumulative damage effects of transportation				0.70 (G)
Failure modes due to pressurization (H)				
Unbond at grain termination due to deviatoric normal tension forces	40	200 (I)	167	3.18
Hoop strain failure in bore	6.7	20 (I)	16.7	1.49

(6) Notes

(A) Include the required safety factors of 2 on bondlines and 1.5 on the propellant.

(B) Allowables have been reduced by a factor of 1.2 to account for the effects of chemical aging. A *batch-to-batch reduction factor* of 1 is used, as the allowables are the specified minimums.

(C) Uniaxial endurance stress at 2 yr at 60°F is estimated to be the same as the uniaxial endurance stress at 1 yr at 70°F.

(D) Biaxial endurance strain at 2 yr at 60°F is estimated from the specified uniaxial endurance strain a 1 yr at 70°F.

(E) Appropriate endurance stress and strain values at -20°F at 1 day are estimated from the specified minimum properties.

(F) Standard rate JANNAF stress has been increased by a factor of 2 to account for the improvement due to high rate shock loadings.

(G) Cumulative damage margins of safety for combined loading conditions are computed as follows:

$$MS = FS_c - 1 \text{ where } \frac{1}{(FS_c)^a} = \frac{1}{(FS_1)^b} + \frac{1}{(FS_2)^c} + \ldots$$

and a,b,c, etc. are the relevant endurance curve slopes.

(H) The pressurization analysis is inherently *conservative as it assumes pressure* does does not occur between the case and cartridge. The cartridge thus deflects radially outward until it contacts the steel motor case.

(I) The standard rate JANNAF stress at 70°F has been increased by a factor of 4 to account for the effects of high strain rate improvement and pressure field enhancement. The JANNAF *strain* has not be increased for these effects.

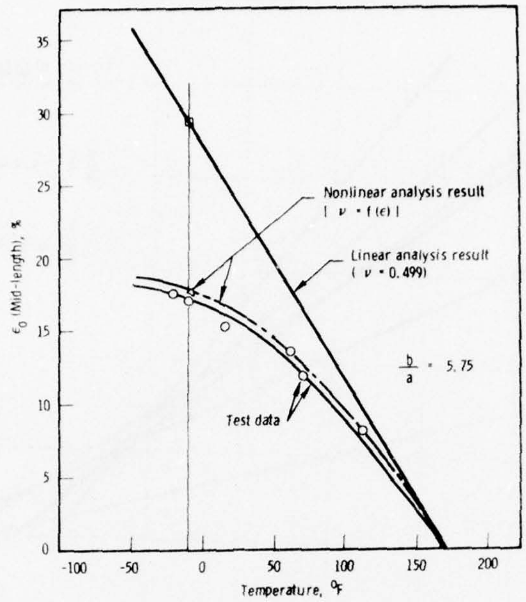

Figure 21. Example of Nonlinear Behavior of UTP-15,908 (90% Solids HTPB) in a Circular Port Motor

07371

economical analysis method. Although this is an elastic analysis method, the viscoelastic behavior of a grain is adequately represented by selection of a uniform grain modulus from relaxation modulus data. Nonlinear effects demonstrated by dilatation or a nonlinear stress/strain curve can also be represented in a simplified manner for use in this program by using the Von Mises expression for the effective stress in an element and selecting an appropriate modulus for each element based on a uniaxial stress/strain curve for the applicable loading rate. By making one or two iterative solutions with the finite element program, the stress and strain in each element can be made to form a pair consistent with the stress/strain curve.

The model used for this analysis is shown in figure 24. The locations of the lowest margins of safety are shown in figure 25, which is the profile of the grain deformed by a thermal load.

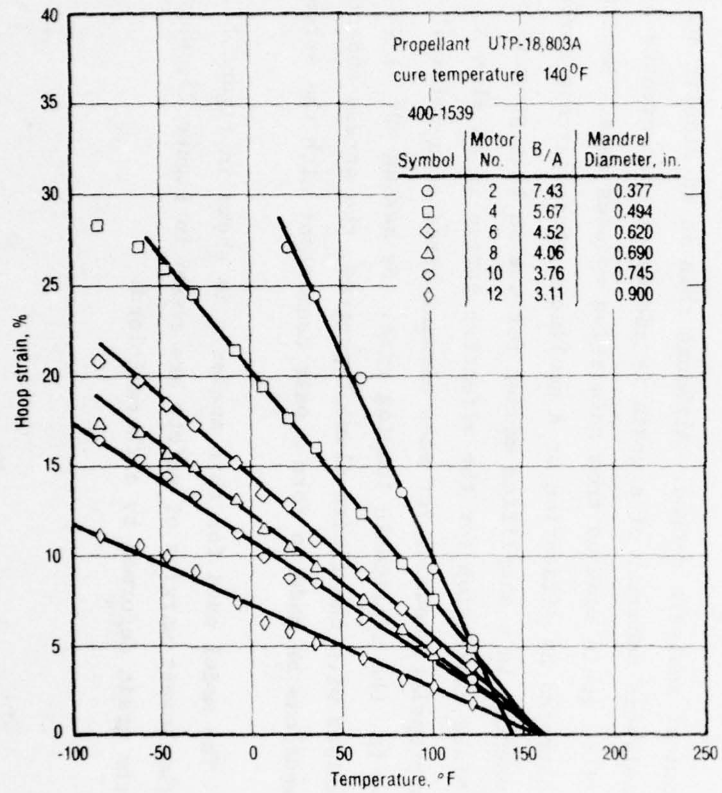

Figure 22. Strain Evaluation Cylinder Data

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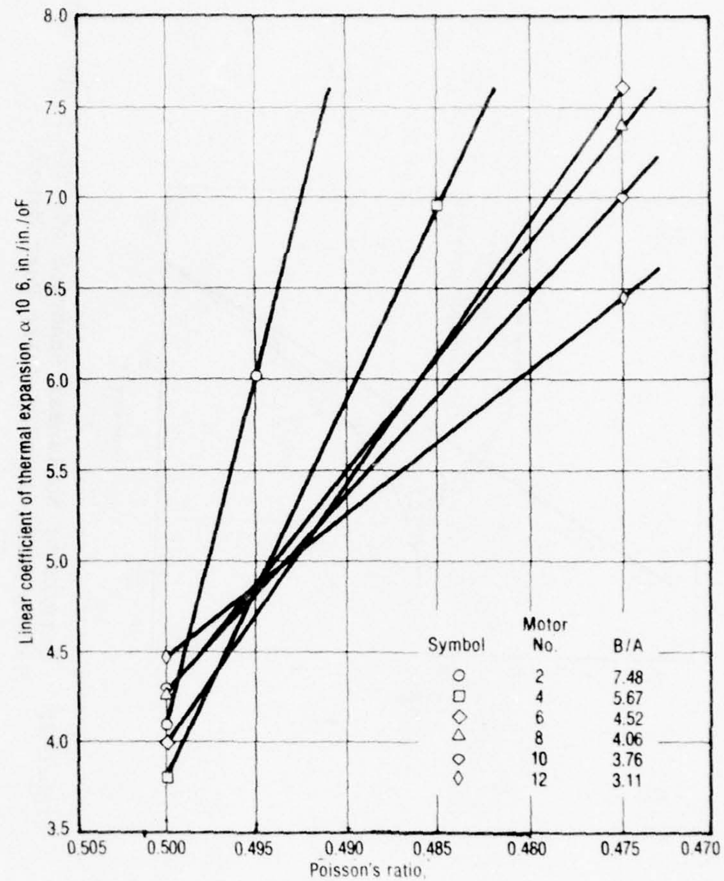

Figure 23. Poisson's Ratio vs Linear Coefficient of Thermal Expansion

12633

TABLE 19. PRINCIPAL STRUCTURAL ANALYSIS COMPUTER PROGRAMS

T0431

Label	Capability	Source
AMG 032 (CSD No. LI65ZZZ)	Finite element; Axisymmetric isotropic continuum; orthotropic shell; linear strain elements; CSD.	Rohm & Haas Co. Huntsville, AL
AMG 033 (CSD No. LI82ZZZ)	Finite element; plane isotropic continuum; orthotropic shell perpendicular to plane of analysis; linear strain elements.	Rohm & Haas Co. Huntsville, AL
SAAS III (CSD No. LI77ZZZ)	Finite element; axisymmetric orthotropic continuum; linear strain elements.	Aerospace Corp. San Bernardino, CA
BOSOR	Finite difference; orthotropic layered shell; nonsymmetric loads; stress, stability, and dynamic response.	Lockheed MSC, Inc. Palo Alto, CA
STAGS	Finite difference; orthotropic layered shells of general shape; nonuniform loads; stress and stability calculations. Nonlinear geometric response.	Lockheed MSC, Inc. Palo Alto, CA
NASTRAN	General structural analysis program.	NASA
TEXGAP	Finite element; axisymmetric orthotropic continuum; orthotropic shell; higher order elements; nonsymmetric loads; fracture mechanics elements.	University of Texas/ CSD
AMG 038 (CSD No. LI94ZZZ)	Finite element; axisymmetric isotropic continuum; orthotropic shell; nonsymmetric loads; linear strain elements.	Rohm & Haas Co. Huntsville, AL
SAP III	General structural analysis program; includes a higher order three-dimensional element and various plate and beam elements.	University of California, Berkeley, CA
SA034 SA035 SA036 SA037	Nonlinear, two-dimensional viscoelastic solid propellant grain analysis	AFRPL Edwards AFB, CA

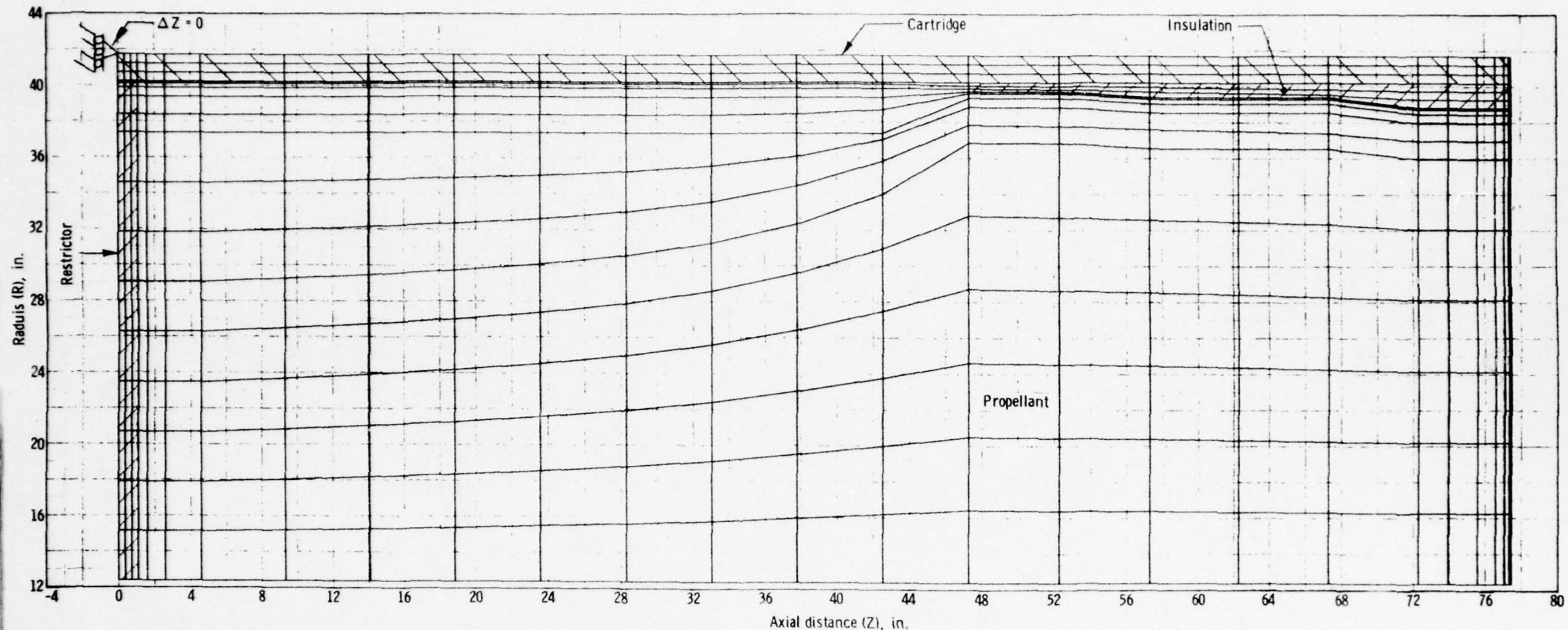

Figure 24. Extended Length Super HIPPO Cartridge Grain

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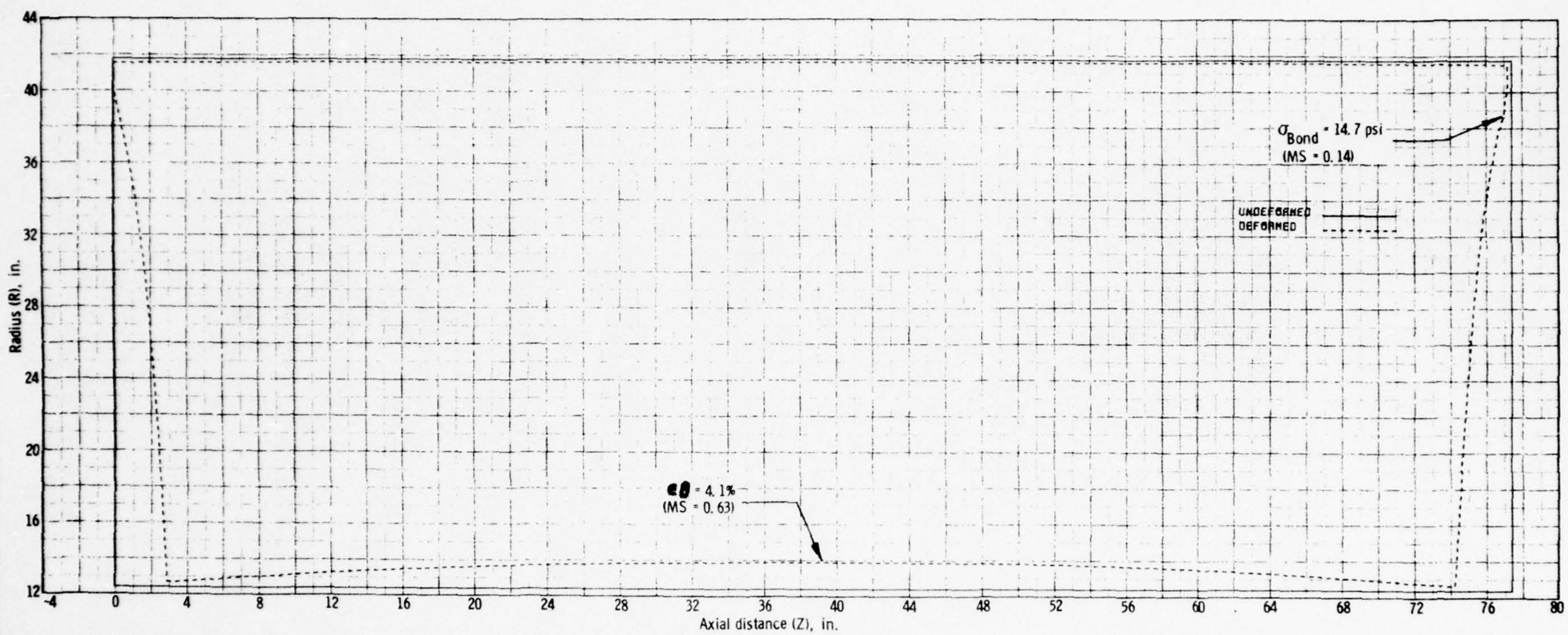

Figure 25. Deformed Grain for Cooldown to 60°F (Deformations Magnified by a Factor of Five for Clarity)

07380

The stress and strain components used for cooldown and storage failure analysis were the bore hoop strain for bore cracking and the maximum principle stress for bond termination failures. These were compared with the measured endurance failure strain in a biaxial stress field and the measured endurance uniaxial stress, respectively. The values were obtained from tests at the temperatures which give the minimum safety factors.

For motor pressurization, the bore strain was again used for the determination of bore failure, but the maximum deviatoric stress was used for bond failure calculations. The failure properties used were measured at the appropriate temperature and loading rate and in a pressure environment equal to chamber pressure in the motor following ignition.

The linear cumulative damage theory was used.

4.2 PHASE II — PROPELLANT PROCESSING AND QA FOR ESLH GRAINS

Phase II encompassed the casting of 20 ELSH cartridges for delivery to AFRPL. The specific loaded ELSH cartridges delivered to AFRPL are itemized in table 20.

TABLE 20. DELIVERED ELSH GRAINS

Part No.	Serial No.	Cast Date	End Use
C11479-01-01	2579-01	9 Apr 76	P-1
	2579-07	8 Jul 76	P-1
	2579-09	22 Jul 76	P-2
	2579-13	24 Aug 76	*
	2579-14	25 Aug 76	P-2
	2579-17	8 Jun 77	*
	2579-19	2 Aug 77	*
	2579-21	30 Aug 77	*
	2579-22	31 Aug 77	*
	2579-23	28 Sep 77	*
C11479-02-01	2579-02	10 Apr 76	P-1
	2579-12	11 Aug 76	*
	2579-15	5 Oct 76	P-2
	2579-20	3 Aug 77	*
	2579-24	29 Sep 77	*
C11479-03-01	2579-08	9 Jul 76	*
	2579-10	23 Jul 76	*
	2579-11	10 Aug 76	P-1
	2579-16	6 Oct 76	*
	2579-18	9 Jun 77	P-2

*Not fired as of 1 Nov 1977.

4.2.1. Summary

This section presents an overview of the propellant produced and the results of the propellant ballistic and mechanical property evaluations. The raw data used in the data summaries which follow are presented in volume II.

Since the ELSH and 84-in. CHAR motors (program phases II and IV) were cast together, the discussions which follow with respect to propellant processing, QA, and properties also include, by necessity, the propellant data for the 84-in. CHAR grains.

4.2.1.1 Propellant Formulation

The propellant used for casting the ELSH (and CHAR) cartridges was a 90% solids, 21% aluminized, HTPB (BDR-45M) formulation designated as UTP-18,803A. The propellant formulation is given in table 2 and in propellant specification SE0719 (appendix B). Some of the key properties of UTP-18,803A, summarized in table 3, are discussed in greater detail in subsequent sections of this document.

4.2.1.2 Batch Summary

Table 21 presents a summary of all the propellant batches made and identifies the specific chemical lots used for each production run.

4.2.1.3 UTP-18,803A Motor Burning Rate

CSD used the 4-lb motor as the standard ballistic test motor for evaluating cured UTP-18,803A. The characteristics of the 4-lb motor are provided below:

Propellant weight, lb	4.0
Grain OD, in.	4.50
Grain ID, in.	3.30
Grain length, in.	8.40
Web, in.	0.60
Initial burning surface, in.	102.0
Change in burning surface, %	±0.75
Maximum P_c, psi	4,000
Maximum thrust, lb	15,000

The accuracy of the 4-lb motor in predicting propellant burning rate in larger motors was demonstrated by comparing over 500 4-lb motor tests with approximately 75 15-lb BATES, 15 70-lb BATES, and three 84-in. CHAR firings. As shown in figure 4, there was no motor size effect on the burning rate of UTP-18,803A (i.e., the 4-lb motor burning rate was the same as that calculated for the 15-lb BATES, 70-lb BATES, and 84-in. CHAR motors).

TABLE 21. UTP-18,803A PRODUCTION SUMMARY

Cast Date	Batch No.	No. of Batches	Fuel Premix No.	AP Grind Ratio	Equivalence Ratio	AP* Lot No.	BDR Lot No.	Al Lot No.	HX-752 Lot No.	IDP Lot No.	IPDI Lot No.	Cartridges Cast
9 to 10 April 76	400-1454 to 400-1465	12	3500-1	Various	0.85	150	20	68	8	8	3	Two ELSH, one Char
28 to 30 April 76	400-1468 to 400-1479	12	3500-2	65/35	0.85	150	20	68	8	8	3	Two ELSH, two Char
10 to 11 May 76	400-1480 to 400-1491	12	3500-3	65/35(five batches) 66/34(seven batches)	0.85	150	20	68	8	8	3	Two ELSH, two Char
8 to 9 July 76	400-1495 to 400-1503	9	3500-3	66/34	0.85	150	20	68	8	8	3	Two ELSH
22 to 23 July 76	400-1505 to 400-1515	11	3500-4	66/34	0.82	150	20	68	8	8	3	Two ELSH, two Char
10 to 12 August 76	400-1516 to 400-1526	11	3500-5	68/32(10 batches) 66/34(one batch)	0.82	150	20	68	8	8	3	Two ELSH, two Char
24 to 26 August 76	400-1527 to 400-1537	10	3500-5	67/33	0.81	150	20	68	8	8	3	Two ELSH, one Char
15 to 16 September 76	400-1539 to 400-1543	5	3500-6	67/33	0.81	150	20	68	8	8	3	Two Char
5 to 7 October 76	400-1546 to 400-1557	12	3500-6	68/32	0.82	150	20	68	8	8	3	Two ELSH, one Char
8 to 9 June 77	400-1574 to 400-1582	9	3500-7	67/33	0.81	150	22	68	8	9	3	Two ELSH
2 to 3 August 77	400-1588 to 400-1600	13	3500-8	67/33	0.81	150B	20 and 22	68 and 69	8 and 10	9	3	Two ELSH, one Char
30 to 31 August 77	400-1606 to 400-1615	10	3500-9	65/35(one batch) 68/32(one batch) 66/34(eight batches)	0.81	150B	22	69	10	9	3	Two ELSH
28 to 29 September 77	400-1620 to 400-1629	10	3500-10	65/35(one batch) 66/34(nine batches)	0.81	150B	22	69	10	9	2	Two ELSH

136 batches ≅ 730,000 lb of propellant

4.2.1.4 UTP-18,803A Physical Properties

As is typically the case for composite solid propellants, the mechanical properties of UTP-18,803A are readily tailored by variations in the curative equivalence ratio (NCO/OH). This affects the binder crosslink density and, therefore, the values of stress, strain, and modulus which depend on crosslink density. During the ELSH production runs, NCO/OH ratios were varied between 0.85 and 0.81 for different groups of batches to observe the responses of mechanical properties. (During the ELSH propellant characterization work discussed in section 4.1.2.1, NCO/OH ratios were examined over a range of 0.86 to 0.80.) The data are plotted as the averages for the mixes made at each level of equivalence ratio in figure 26. Although strain at maximum stress values appear to be affected only minimally as crosslink density and modulus are varied, the high rate pressurized strain values are fairly sensitive to and well correlated with the modulus values obtained in low rate unpressurized tests (figure 27).

Part of the effort under contract No. F04611-76-C-0010 was aimed at statistically evaluating the processing and physical properties of UTP-18,803A. Table 6 presents a summary of the primary properties monitored during the series of full-scale production runs.

Figure 28 presents a comprehensive package of mechanical property data measured on ELSH batch 400-1539 which was used in the characterization of UTP-18,803A propellant. Data include relaxation modulus from -65° to 95°F, uniaxial endurance at constant load and constant strain, biaxial constant strain, and constant load shear endurance. All endurance tests were conducted at 20°F, since this temperature represents the worst case conditions for motor design purposes. Figures 22 and 23 show results of cool-to-failure tests on a series of strain evaluation cyclinders having B/A values ranging from 3.1 to 7.4 (ELSH had a B/A of 3.24 and CHAR had a maximum B/A of 3.44). The SEC with the highest B/A failed at 40°F with 24% bore strain. No other failures occurred although the remaining SECs were cooled to -85°F, with bore hoop strains exceeding 28% at this temperature.

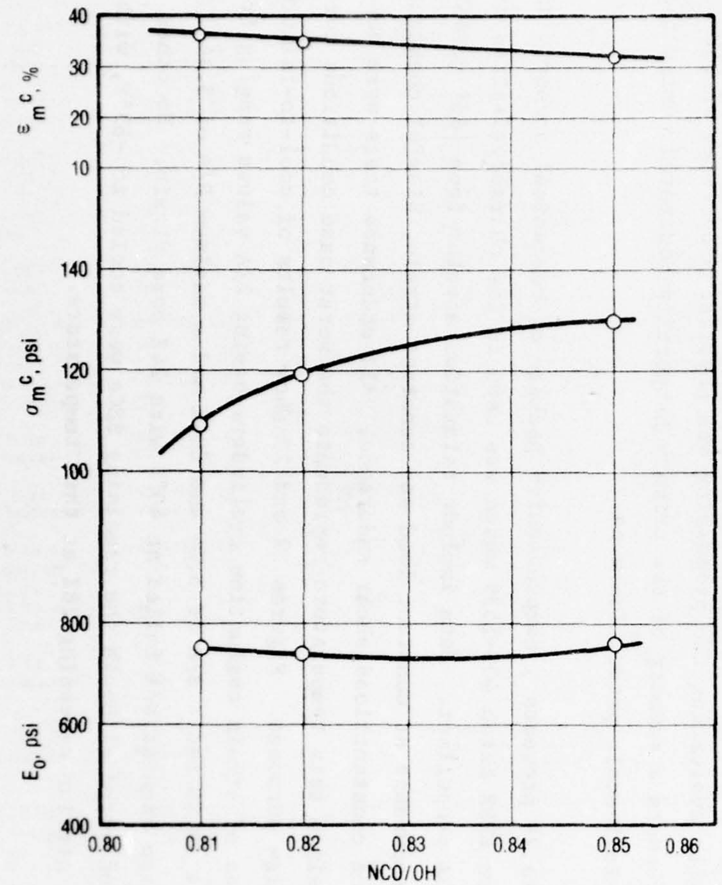

Figure 26. Uniaxial Properties vs Curative Ratio

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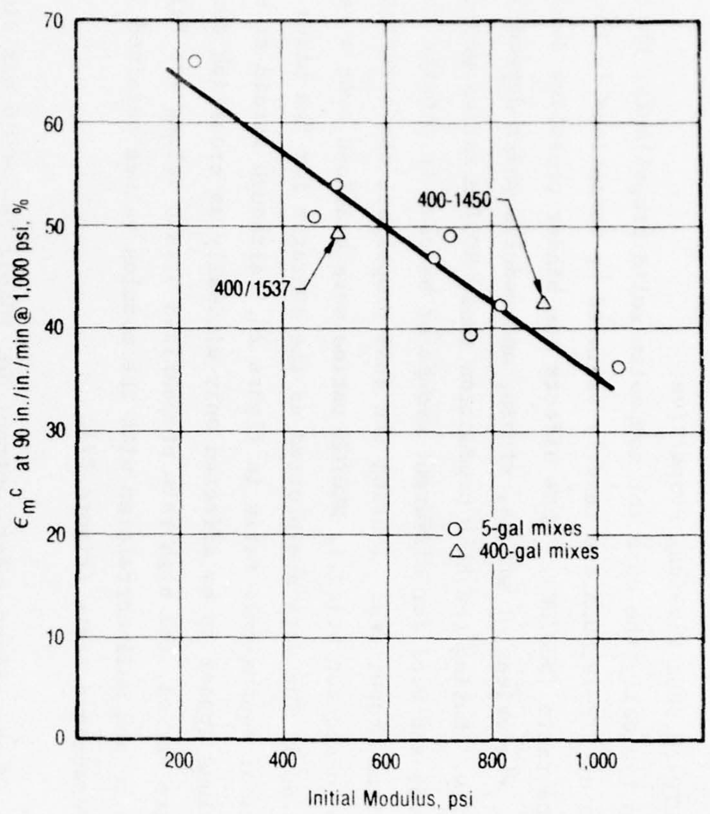
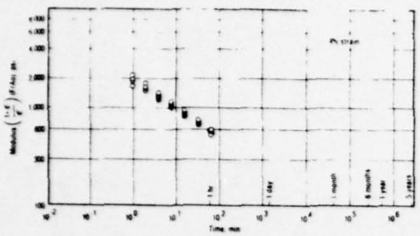
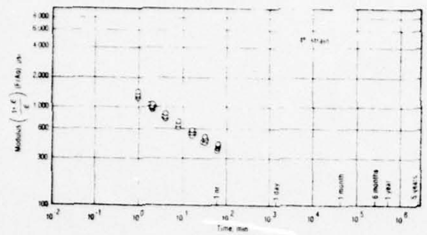


Figure 27. High-Rate Pressurized Strain vs Initial Modulus

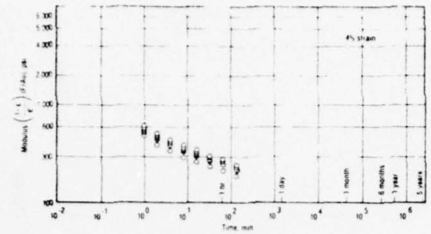
12637



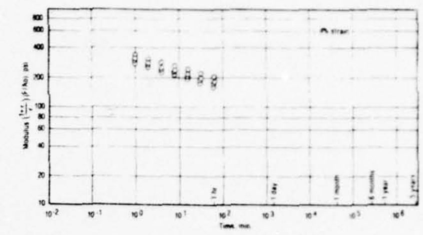
Stress Relaxation Modulus, -65°F
12638



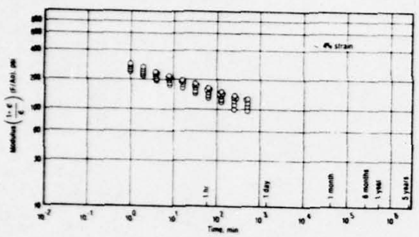
Stress Relaxation Modulus, -45°F
12639



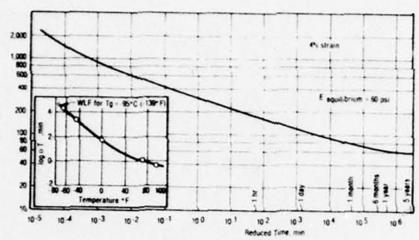
Stress Relaxation Modulus, 0°F
12640



Stress Relaxation Modulus, 70°F
12641



Stress Relaxation Modulus, 95°F
12642



Master Modulus Relaxation Data
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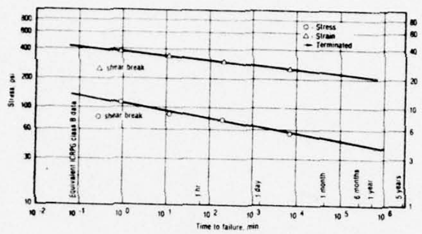
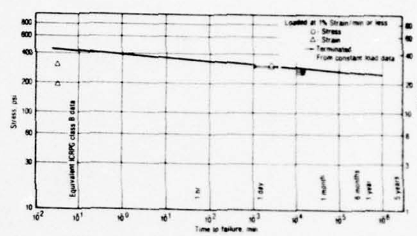
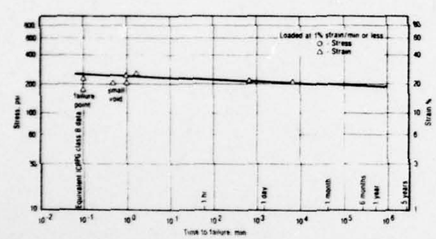


Uniaxial Endurance Data
12644



Uniaxial Endurance Data
12645



Biaxial Endurance Data
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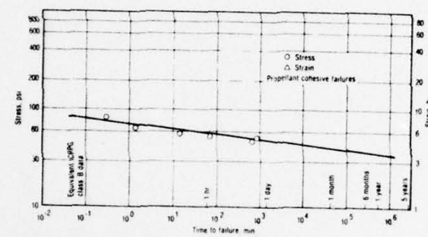

Shear Endurance Data, UTP-18,803A
12647

Figure 28. Mechanical Property Data, ELSH Batch 400-1539

4.2.2 Casting Tooling Design and Fabrication

The casting tooling for the ELSH cartridges is defined as P/N C12026 and P/N C12031. P/N C12026 defines the casting core, baseplates, and associated hardware while P/N C12031 defines the tooling for casting the aft configuration for loaded cartridge P/N C11479-03-01.

The tooling for the ELSH (and CHAR) cartridges offered a design challenge to provide low-cost reliable tooling which could be used to lift a loaded propellant cartridge from the casting oven in the uncured state, if necessary. Figure 29 illustrates the ELSH casting tooling.

The baseplate was designed to shoulder the weight of the entire loaded cartridge. A lifting stem was provided to transmit the load of the cartridge, propellant (25,000 lb) and tooling to a single point at the aft end of the loaded cartridge.

The aft ring of the ELSH casting tooling (figure 29) was made to provide for centering of the aft end of the core and for holding the cartridge down during casting, moving, and curing operations. In no case are any lifting loads applied to the ring.

Process tooling utilization is discussed further in sections 4.2.3.2, 4.2.3.6, and 4.2.3.7 of this report.

4.2.3 Propellant Processing and Quality Assurance

The following discussion describes the propellant processing procedures and the QA verifications used in casting the ELSH loaded cartridges. The processing specification for UTP-18,803A (SE0720) is presented in appendix C. The O&QR and the IQOP for the three ELSH cartridge configurations identified as P/N C11479-01-01, P/N C11479-02-01, and P/N C11479-03-01 are given in appendices D, E, and F, respectively.

The general propellant processing logic used in casting the ELSH cartridges is illustrated in figure 30. Table 22 presents a summary of the QC inspections,

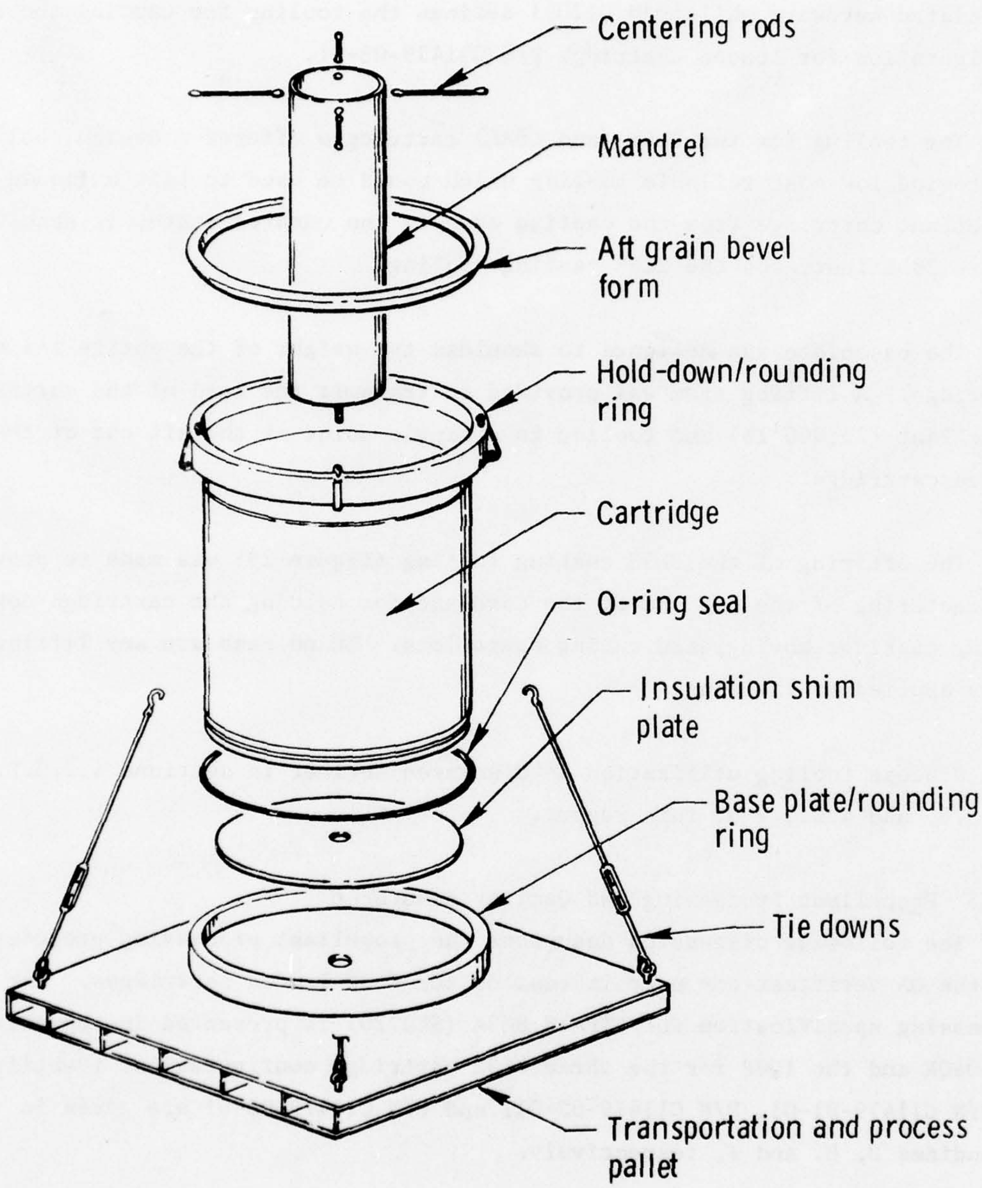

Figure 29. Basic Tooling Concept for CHAR and Super HIPPO Cartridges

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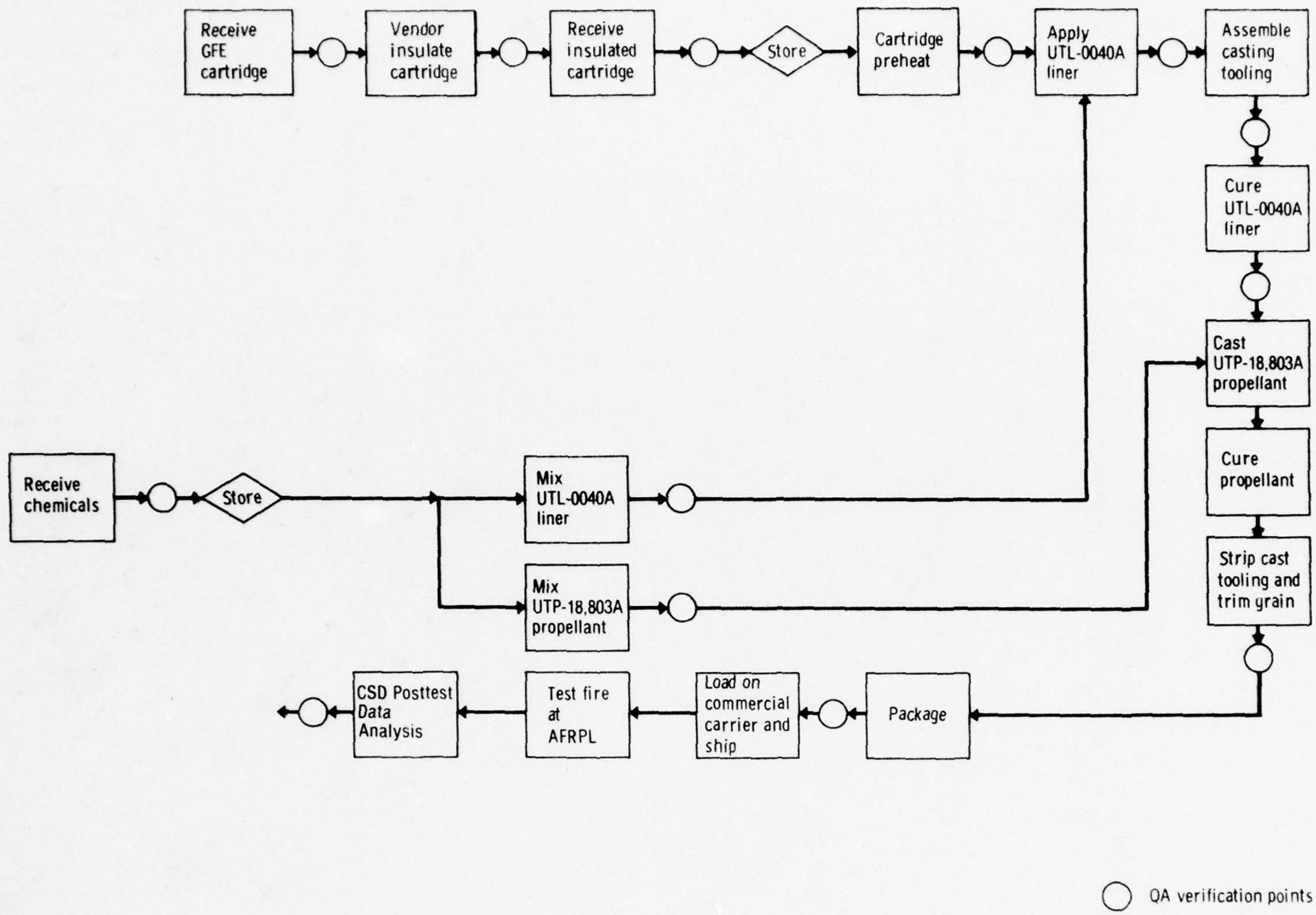

Figure 30. Process Flow Diagram for ELSH Cartridges
(P/Ns C11479-01-01, -02-01, and -03-01)

07375R-2

TABLE 22. SUMMARY OF INSPECTIONS/TESTS AND ACCEPTANCE CRITERIA

T0421R

Level of Inspection	Inspection: Inspection/Test	Inspection: Reason for Inspection/Test	Acceptance Criteria: Limits	Acceptance Criteria: QC Procedure	Action to be Taken if Not per Specification
Materials and ingredients	See table 23	See table 23	See table 23	See table 23	See table 23
Process tooling	Functional assembly	Verify functionality of process tooling	N/A	QA-C01 or O&QR	Rework as required to assure fit and function
	Mandrel bore dimensional verification	Assure B/P requirements are maintained for ballistic correlations and predictions	Per B/P	QA-C01 or O&QR	Rework to B/P or submit to MRB
	Visual for coating adequacy	Assure that RTV/Teflon-coated areas are uniform and fully covered	100%	QA-C01 or O&QR	Rework to B/P
Insulated cartridge preheat	Monitor and review preheat cycles	Verify that preheat temperature and time meet established procedures	120 hr minimum at 215°F to 225°F	O&QR	Low or high temperature — submit to MRB Too short preheat time — submit to MRB
Liner preparation	See table 24	See table 24	See table 24	See table 24	See table 24
Apply UTL-0040A liner	Weight	Verify that the proper amount of liner was applied	25 lb minimum	O&QR	Add additional liner until 25 lb minimum is achieved
	Visual check of liner coverage	Verify that all surfaces of insulation are covered with liner	100% coverage	O&QR	Add additional liner to achieve 100% coverage
Assembly casting tooling	Monitor and review preheat cycles	Verify preheat (and liner cure) temperature and time meet established procedures	8 hr at 160° ±10°F and 4 hr at 130° ±10°F	O&QR	Low or high temperature — submit to MRB
	Mandrel location	Verify proper mandrel location before casting	Per B/P	O&QR	Rework to B/P
	Weight	Verify assembled casting assembly weight as base for establishing net propellant weight	N/A	O&QR	N/A
Cure UTL-0040A liner	See table 24	See table 24	See table 24	See table 24	See table 24
Propellant mixing	See table 26	See table 26	See table 26	See table 26	See table 26
Casting and cure UTP-18,803A propellant	Monitor and review cure cycle	Verify propellant cure temperature and time to meet specification requirements	10 days at 140°±10°F 24 hr at 70°±10°F	O&QR	Low or high temperature — submit to MRB
Package and ship	Surveillance inspection	Verify packaging and shipping operations per specified requirements	-	O&QR	N/A

tests, and acceptance criteria used for this program. Detailed discussion of propellant processing, including process steps and QA procedures, follows.

4.2.3.1 Materials Control

Materials control includes the timely purchase of all materials required for the program, scheduling for QC acceptance, proper storage, handling, and control of usage of those materials as well as receipt of all GFE items.

4.2.3.1.1 Procedure

Each propellant ingredient was procured as a single lot and stored in specially controlled areas and bonded for use only on contract No. F04611-76-C-0010. This was done by identifying each item with QC project status tags that did not allow the material to be used without the QC laboratory approval. The AP was purchased as a crossblended lot which was characterized in accordance with the recommendations of AFRPL-TR-73-111. The purchased AP oxidizer was stored at the vendor site (PEPCON) until required by CSD. The AP was then shipped to CSD in 5,000-lb flo-bins. The flo-bins were stored inside the oxidizer storage building (station 0300).

A comparison of the CSD specification for AP to the specification in AFRPL-TR-73-111 indicates that the CSD specification is tighter in most respects. Of particular interest are the tighter CSD requirements on sulfonated ash (0.50% vs 0.9%); perchlorate assay (98.5% vs 98.3%); and moisture (total water) 0.065% maximum vs 0.09% (sum of internal and external moisture, 0.02% + 0.07%).

Aluminum was received in truck load shipments of 40,000 lb and stored at CSD building 0331 until use.

BDR-45, IDP, and IPDI were shipped and stored in 55-gal sealed drums at building 0460 until required for use.

HX-752, HX-868, and DDI-1410 were received in small containers which were stored under refrigeration in the cold box at building 0210.

As the Government-furnished cartridges were received, they were visually inspected for conformance to the drawings. American Polytherm, under subcontract to CSD, then insulated the cartridge walls, installed the forward restrictor, installed the Al-227 wedges at the forward end, and applied the 1-in. rubber strip around the cartridge forward end on the cartridges to be used for casting P/Ns C11479-02-01 and C11479-03-01. Figure 31 identifies those items installed by the vendor. Upon receipt of the insulated cartridges in-house, CSD QC inspected them for compliance to the drawing requirements. Any discrepancies were placed on an IDR which was submitted to the MRB for disposition (the MRB included cognizant personnel from Engineering, Operations, QC, and the AFPRO).

4.2.3.1.2 QC and Acceptance Criteria

All chemical raw materials were inspected upon receipt at CSD before release to Operations for use. Routine inspection defined in QC laboratory procedure QC-201 consists of verification of identification, checking for shipping/handling damage or contamination, and review of vendor certifications and test results for compliance to purchase order requirements. Any materials found to be discrepant were tagged as such and the discrepancies submitted to the MRB for dispostion. The MRB consisted of representatives from Engineering, Operations, QC, and the AFPRO. Once the discrepancy had been cleared, the materials were tagged with the appropriate status tags and released to Operations.

In addition, specific verification tests were conducted to corroborate the vendor test data. All such tests were conducted to sampling plans per MIL-STD-414, tables A-2 and C-3, at an inspection level of IV and an AQL of 1.0. Table 23 provides a summary of raw chemicals for the ELSH (and CHAR) loaded cartridges, the parameters verified by CSD's QC laboratory, the reasons for verification, acceptance criteria, and a reference to existing QC laboratory procedures used to conduct the verification. Since extended storage was required for some of the materials, the reinspection period is also reflected in the table. Reinspection requirements are defined in detail in QC laboratory procedure QC-J702.

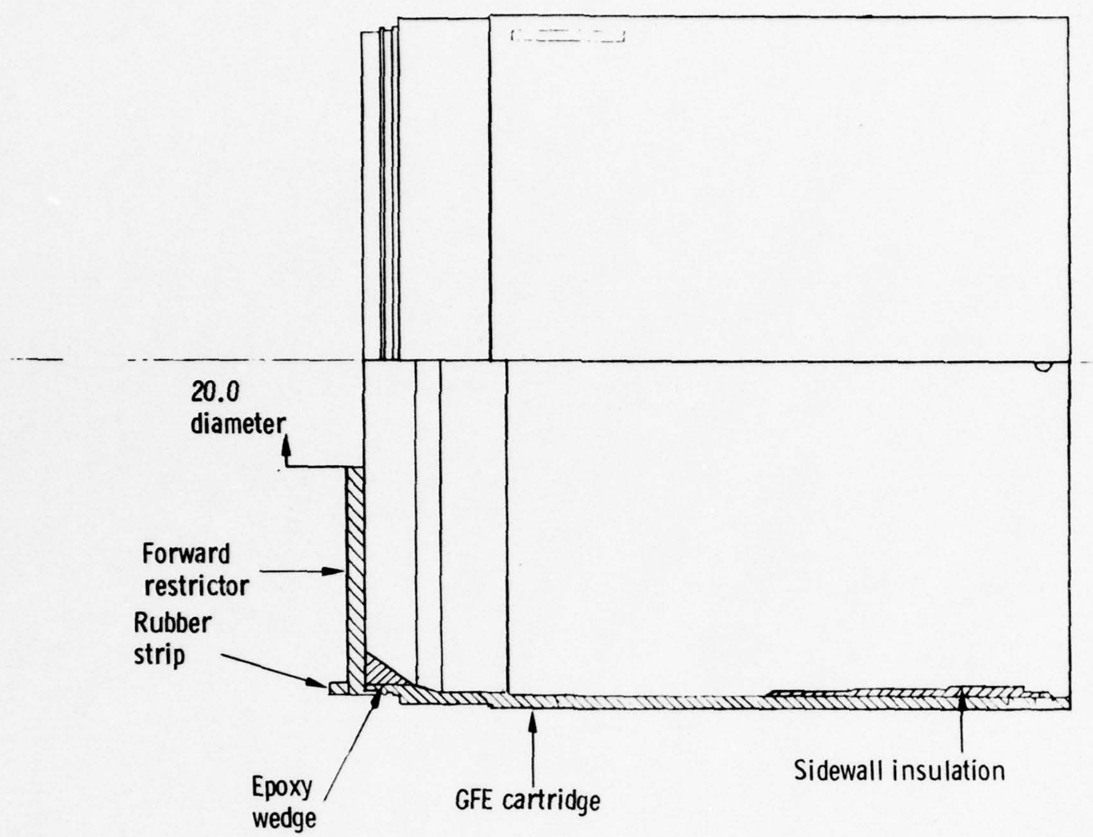

Figure 31. Vendor-Installed Components

07406R

TABLE 23. QC INSPECTION/ACCEPTANCE CRITERIA FOR RAW MATERIALS

T0423R

Propellant/Liner	Raw Material Ingredient	Inspection: Inspection/Test	Inspection: Reason for Inspection/Test	Acceptance Criteria: Limits	Acceptance Criteria: QC Procedure	Action to be Taken if out of Specification
Propellant (UTP-18,803A)	HX-752 (bonding agent)	Imine equivalent weight	Acceptance testing	125 minimum	QC-J703 (6 months)*	Returned to vendor for replacement or submit to MRB
	IDP (plasticizer)	Hydroxyl value	Acceptance testing	0.0050 maximum	QC-L583 (2 yr)*	
	BDR-45M (binder)	Hydroxyl value Water	Required for formulation Water interferes with cure mechanism Maximum allowable acceptance testing	0.075 to 0.008 0.05 maximum	QC-L585 (2 yr)*	
	PRO-TECH® 2705 (anti-oxidant)	Color Melting point	Acceptance testing	Gray 205 to 235° C	QC-J703 (2yr)*	
	Aluminum MD 101 (fuel)	Purity Volatiles Particle size	Required for formulation Acceptance testing Acceptance testing	97.5 minimum 0.1 maximum % 80% – 40/60 micron 50% – 20/40 micron 10% – 4/20 micron	QC-L508 (2 yr)*	
	Ammonium perchlorate (oxidizer)	Assay Water pH Sulfated ash TCP Particle size	Required for formulation Water interferes with cure Acceptance testing Acceptance testing Acceptance testing Required for formulation	98.5% minimum 0.065 maximum % 5.5 to 6.5 0.50 % maximum 0.10 to 0.30 Specification table	QC-L504 and QC-K534 (2 yr)*	
	IPDI (curative)	NCO content (Assay)		109/113	QC-J703 (6 months)*	
Liner (UTL-0040A)	HX-868 (bonding agent)	Imine equivalent weight	Required for formulation	125 to 150	QC-J703 (6 months)*	
	BDR-45M (binder)	Hydroxyl value Water	Required for formulation Water interferes with cure	0.075 to 0.085 0.05 maximum %	QC-L585 (2 yr)*	
	Thermax (carbon black filter)	N/A	N/A	–	N/A	
	DDI (curative)	NCO content (assay) GPC/IR	Required for formulation Identify impurities	96.7 % minimum	QC-L586 (6 months)*	

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4.2.3.2 Process Tooling

The tooling used to cast the ELSH grains under contract No. F04611-76-C-0010 is illustrated in figure 29 and described below.

4.2.3.2.1 Transportation and Process Pallet

This pallet was used to support the cartridge throughout the propellant loading process. Since the process took place in several stations, the pallet was also structurally capable of supporting the loaded cartridge during its transportation through the plant.

4.2.3.2.2 Baseplate/Rounding Ring

Earlier experience in loading glass cartridges showed that they did not stay round during thermal cycles. To ensure that the loaded cartridges met drawing roundness requirements, a machined steel rounding ring was used at each end of the cartridge throughout the process.

4.2.3.2.3 Holddown/Rounding Ring

This machined steel ring served to round the aft end of the cartridge and provided a means to attach tiedown cables to secure the cartridge to the support pallet.

4.2.3.2.4 Mandrels

The mandrel consisted of metal weldments, machined to the correct configuration and Teflon-coated. They provided accurate and reproducible grains throughout the program.

4.2.3.2.5 Cartridge Lifting Fixture

A lift fixture for the ELSH cartridges was provided as GFE. This fixture, defined as P/N C10294-01-01, consisted of steel weldments which attached to the vertical cartridges at the lift holes which were equally spaced around the upper end of each cartridge.

4.2.3.2.6 Mandrel Stripping

The metal mandrels were removed from the cured grains through the use of CSD's hydroset and overhead crane.

When not in use, the tooling was protected and stored to prevent damage or degradation. Upon removal from storage for use, all tooling was checked for functionality and to ensure that the Teflon-coated surfaces were adequate. Upon program completion, the tooling was delivered to the Government as a contract deliverable end item.

4.2.3.3 Cartridge Insulation

As stated earlier, American Polytherm was selected to refurbish/insulate all cartridges for this program under subcontract to CSD. The vendor was responsible for (1) insulation of the cartridge sidewall, (2) installation of the forward restrictor, (3) installation of the fiberglass reinforcing strip and joint protection strip, and (4) installation of the epoxy wedge around the cartridge forward end ID.

4.2.3.3.1 Insulation of Cartridge Side Wall

A. Procedure

The aft side wall of ELSH cartridges was insulated with silica-asbestos loaded Buna-N rubber (ORCO-9250). The rubber insulation was bonded to the cartridge with an epoxy adhesive (EA-921) in three steps; each step insulated approximately one-third of the circumference of the cartridge.

B. QC and Acceptance Criteria

Upon receipt of the insulated cartridge in-house, the insulation was visually inspected for proper location and 100% bond at the edges. Any unbonded areas were repaired by injecting EA-921 into them with a caulking gun and curing.

4.2.3.3.2 Forward Restrictor Installation

A. Procedure

The restrictor was bonded to the forward end of each of the cartridges with an epoxy adhesive. The restrictor is a disc of silica-asbestos-filled buna-N rubber (ORCO-9250).

B. QC and Acceptance Criteria

Upon receipt in-house, the insulated cartridge was inspected for restrictor location and unbonded area. All unbonded areas were repaired by an EA-913 injection followed by adhesive cure.

4.2.3.3.3 Installation of Fiberglass Reinforcing Strip and Joint Prctection Strip

A. Procedure

A woven fiberglass reinforcing strip was bonded to the forward end of the cartridge OD to reinforce the restrictor to cartridge bond.

B. QC and Acceptance Criteria

Upon receipt in-house, the joint protector was inspected for proper location and unbonds. Any unbonds were repaired using EA-913 adhesive.

4.2.3.3.4 Installation of Epoxy Wedge

A. Procedure

The versamide/epoxy wedge around the cartridge forward end ID was cast in place and cured. The nominal sealent formulation by weight was 66.7% versamide 125 resin and 33.3% ERL-2795 epoxy resin.

B. QC and Acceptance Criteria

Upon receipt in-house, the epoxy wedge was inspected for proper location, unbonds, and cracking. Any unbonds or cracks were repaired by filling with EA-913 adhesive.

4.2.3.4 Cartridge Preheat

Before application of the liner, the insulated cartridge was subjected to a preheat cycle at 215°F ± 5°F for a minimum of 120 hr.

4.2.3.5 Liner Preparation

4.2.3.5.1 Procedure

Liner UTL-0040A (see appendix J for the liner specification) was used for the ELSH (and CHAR) cartridges. The nominal composition of the liner is given below:

Material	Chemical Equivalents	Nominal Wt-%
BDR-45M	1.0	41.8
HX-868	-	6
Thermax	-	40
DDI-1410	1.25	12.2

UTL-0040A was mixed in a 5-gal planetary blade mixer (figure 32) which has a capacity of 80 lb of liner, sufficient for lining two cartridges.

All chemical ingredients used were analyzed and accepted before use. A double weighing/double operator check of ingredient weights was used. All ingredients for the 5-gal mix station were weighed in a separate weighout room. A separate set of scales in the mixer building was used to reweigh ingredients just before addition to the mixer. Mixing operations and all materials used were controlled by process operating procedures and O&QRs. The basic process steps for mixing UTL-0040A liner are shown in figure 33.

A premix of two-thirds of the BDR-45M polymer and two-thirds of the HX-868 was made by mixing at 120°F for 10 min. Less than the fully required amount of the BDR-45M was used to achieve a high viscosity mix of polymer and Thermax. Following this initial premix step, the Thermax was loaded into the screener-feeder and a vacuum applied to the system (10 mm Hg absolute pressure). The Thermax was then added and mixed into the polymer premix at a predetermined rate. Mixing was continued for 10 min beyond the time of

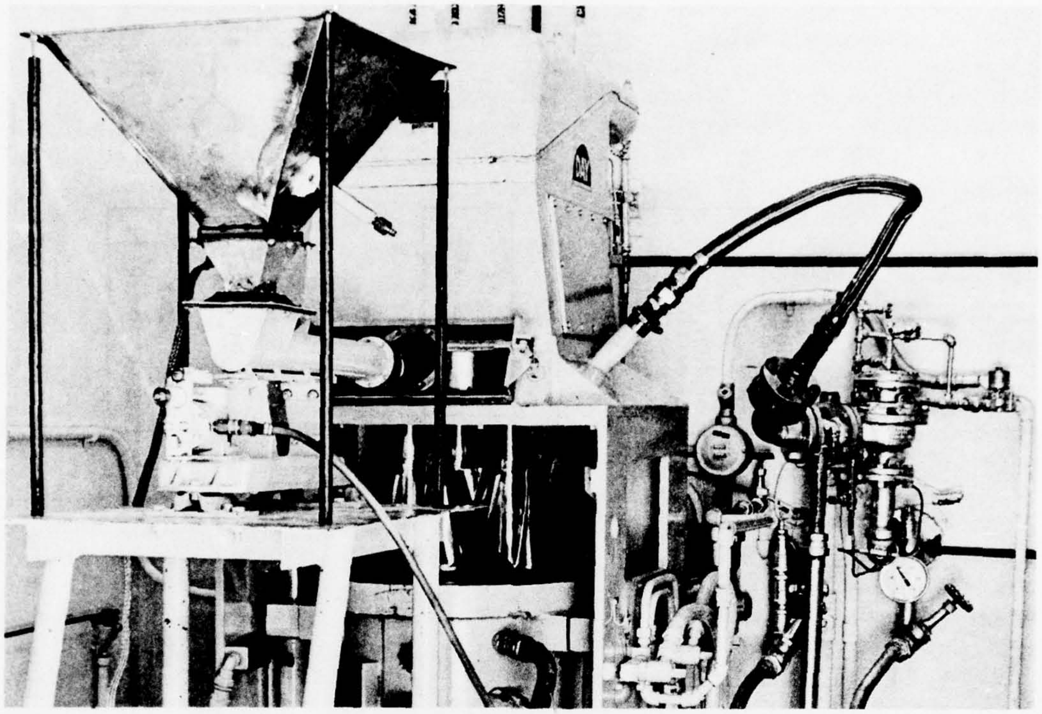

Figure 32. Liner Mixer

the last Thermax addition. The mix bowl was lowered, the blades scaped down and the remaining one-third of the BDR-45M polymer added. The bowl was raised and mixing continued for 10 min at low speed to incorporate the liquid polymer. Vacuum was applied to the bowl (10 mm Hg absolute pressure) and mixing continued for 30 min at high speed at 120°F.

Curative was added to the bowl and mixed for 10 min at low speed to avoid splashing and loss of curative to the upper mixer head. An additional mix time of 15 min under vacuum at high speed was followed by blade scrape-down and another 15-min vacuum mix cycle at high speed and 120°F.

4.2.3.5.2 QC and Acceptance Criteria

QC samples were withdrawn to determine correct premix and final mix formulation. Table 24 provides a summary of the inspection and test and the associated acceptance criteria.

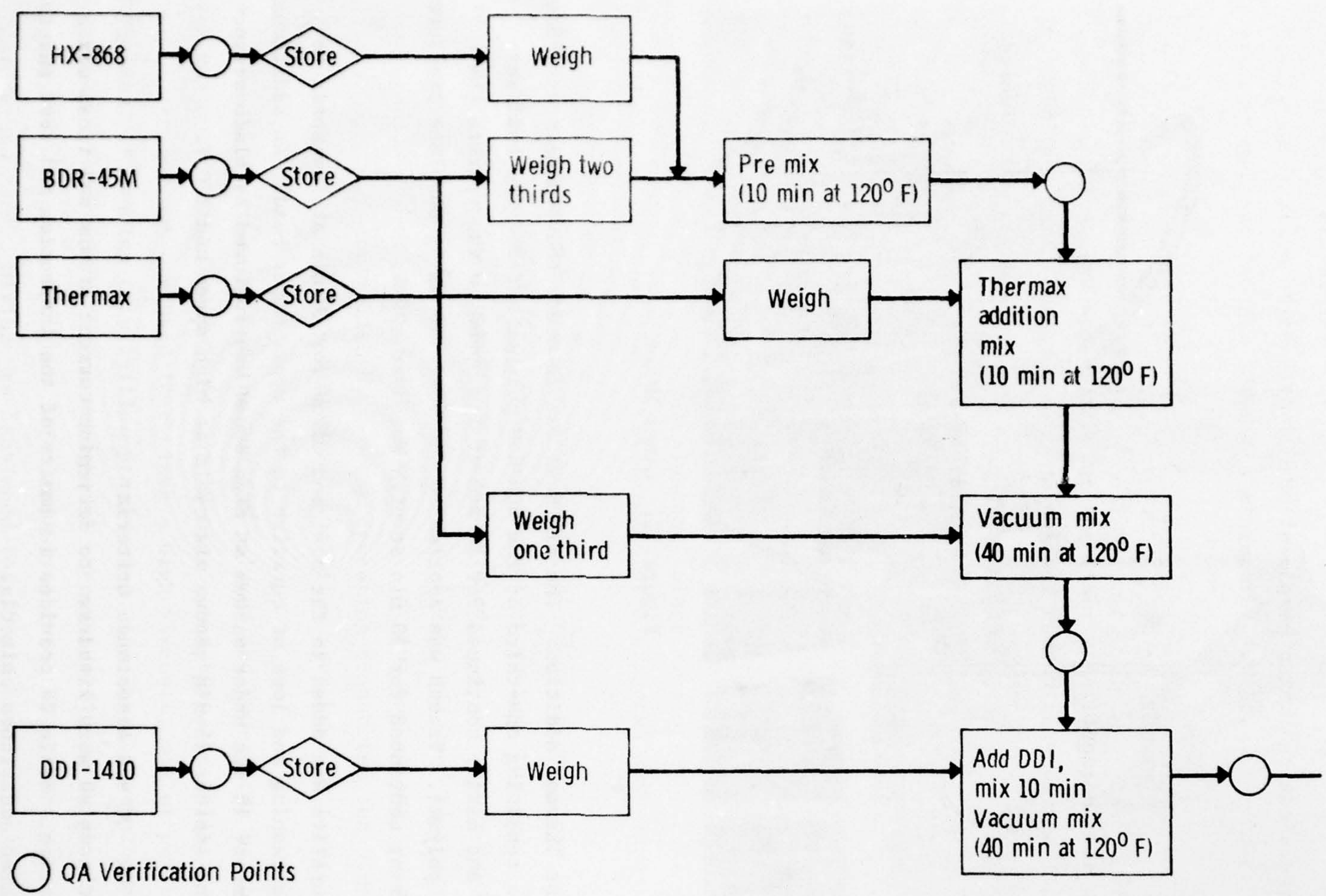

Figure 33. Flow Diagram for Liner Mixing Process

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TABLE 24. INSPECTIONS, TESTS, AND ACCEPTANCE CRITERIA FOR UTL-0040A

Inspection			Acceptance Criteria		
Level of Inspection	Inspection/Test	Reason for Inspection/Test	Limits	QC Procedure	Action to be Taken if Not Per Specification
Ingredient					
BDR-45-M	H_2O content GPC/IR	To detect any deleterious storage and aging effects (material always) analyzed immediately before use).	0.05% maximum	QC-K522	Degas to achieve in specification condition
DDI	Assay Dimmer GPC/IR	Formulation purposes To detect storage of environmental effects	96.7% minimum	QC-L585	Dimer above specification - scrap Assay out of specification - scrap
Premix A: (HX-868 + two-thirds BDR-45M)	H_2O content HX-868 content	Moisture can degrade cure Essential to liner physical properties	0.03% maximum 6.26 to 7.40%	QC-K522	Degas to achieve in specification condition Re-sample and if still out scrap
Premix B: (Premix A + Thermax	None	N/A	-	N/A	N/A
Premix C: (Premix B + one-third BDR-45M	Solids GPC-IR	Verification of formulation	43.26 to 47.81%	QC-N512	Low - Add solids High - Add BDR-45M to bring into specification
Liner (In-process) (Premix C + DDI)	DDI GPC/IR	Verification and acceptance	9.70% minimum	IQCL-4011	High - Re-sample and if still out, scrap Low - Add DDI to bring into specification
Cured liner	Peels	Post process assurance that material did cure and give the desired bond strength (liner to insulation)	4 lb/in. width minimum	QC-N618 QC-N605	Submit to MRB

4.2.3.6 Application of UTL-0040A Liner

4.2.3.6.1 Procedure

Before the preheat (section 4.2.3.4), the insulated cartridge was solvent wiped as a final cleaning step. Any traces of residual solvent were removed during the preheat cycle which followed. The cartridge was then cooled so that the wall temperature was between 100° and 130°F before the UTL-0040A liner application.

Approximately 25 lb of QC-accepted UTL-0040A liner was applied to the cartridge sidewall and forward restrictor. The liner was applied manually using a brush and scraper with the cartridge in a vertical position. Figure 34 shows the lining of a cartridge. As shown, the liner is black so any skips or misses of coverage are easily detected and reworked.

The liner was precured in the casting oven (section 4.2.3.7.1) just before propellant casting to avoid overcuring the liner.

Figure 34. Application of UTL-0040A Liner to Cartridge Wall

4.2.3.6.2 QC and Acceptance Criteria

Liner samples were prepared from the liner batch used to line the cartridge. These included one sample tray for mechanical properties and one peel tray for liner/insulation and case/propellant adhesion data. The samples were sent to the casting station to be cast with the cartridge. QC verification steps included verification of liner weight and verification that all internal surfaces of the insulated cartridge were covered with liner (table 22).

4.2.3.7 Assemble Casting Tooling and Precure Liner

4.2.3.7.1 Procedure

The Teflon-coated mandrel was installed into the lined cartridge (figure 35) and secured to the forward face of the lined restrictor through the casting baseplate. Aft centering rods were installed between the mandrel and the ID of the cartridge to effect core centering. The completed casting assembly was then weighed. After weighing, the cartridge was transported to the vacuum casting and curing oven. Once removed from the transporter, it was placed in the oven, and leveled as required with all moves completed before final alignment of the core for casting. A lift chain block (figure 36) was used to prevent the chain used in lifting the cartridge from dropping into the core. The lift chain block is installed through the "pear link" and holds the lift chain in position for easy connection.

The oven lid was installed and vacuum checked to ensure no unbonds between the uncured liner and the cartridge. After the vacuum check, the cartridge was heated in the oven for a minimum of 8 hr at 160° ± 10°F to partially cure the UTL-0040A liner. After liner precure, the cartridge was cooled to a temperature of 130° ± 10°F for a minimum of 4 hr before casting.

4.2.3.7.2 QC and Acceptance Criteria

QC inspection points during this operation included in-process checks to verify that preheat cure cycles followed established procedures. Inspection also included verification of mandrel configuration (i.e., correct mandrel for the grain configuration being cast) as well as verification of casting assembly weight to provide propellant weight.

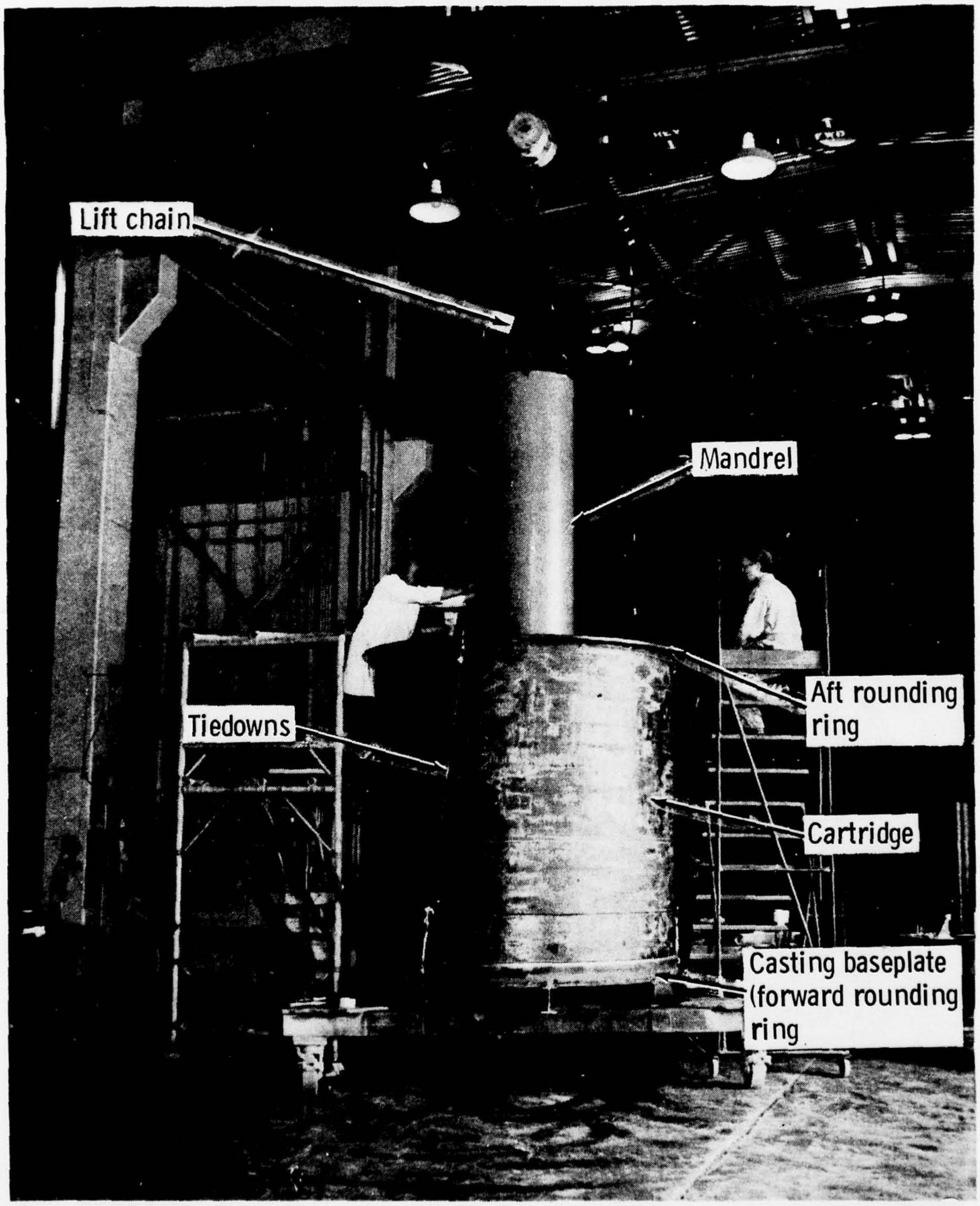


Figure 35. Installation of ELSH Mandrel

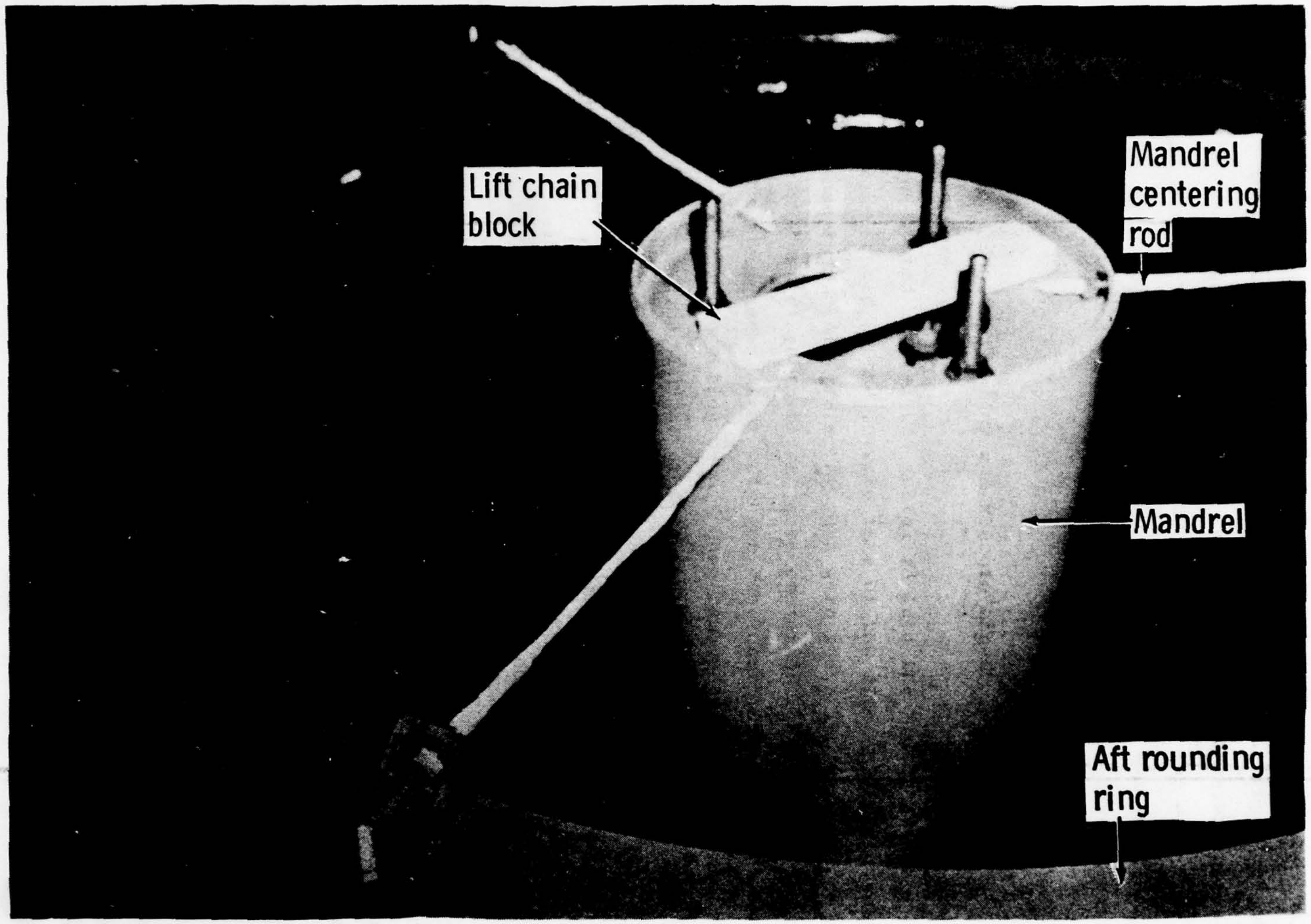


Figure 36. Mandrel Installed in Cartridge

4.2.3.8 Propellant Mixing

Both the propellant and propellant processing specifications are provided in appendices B and C, respectively, to this document.

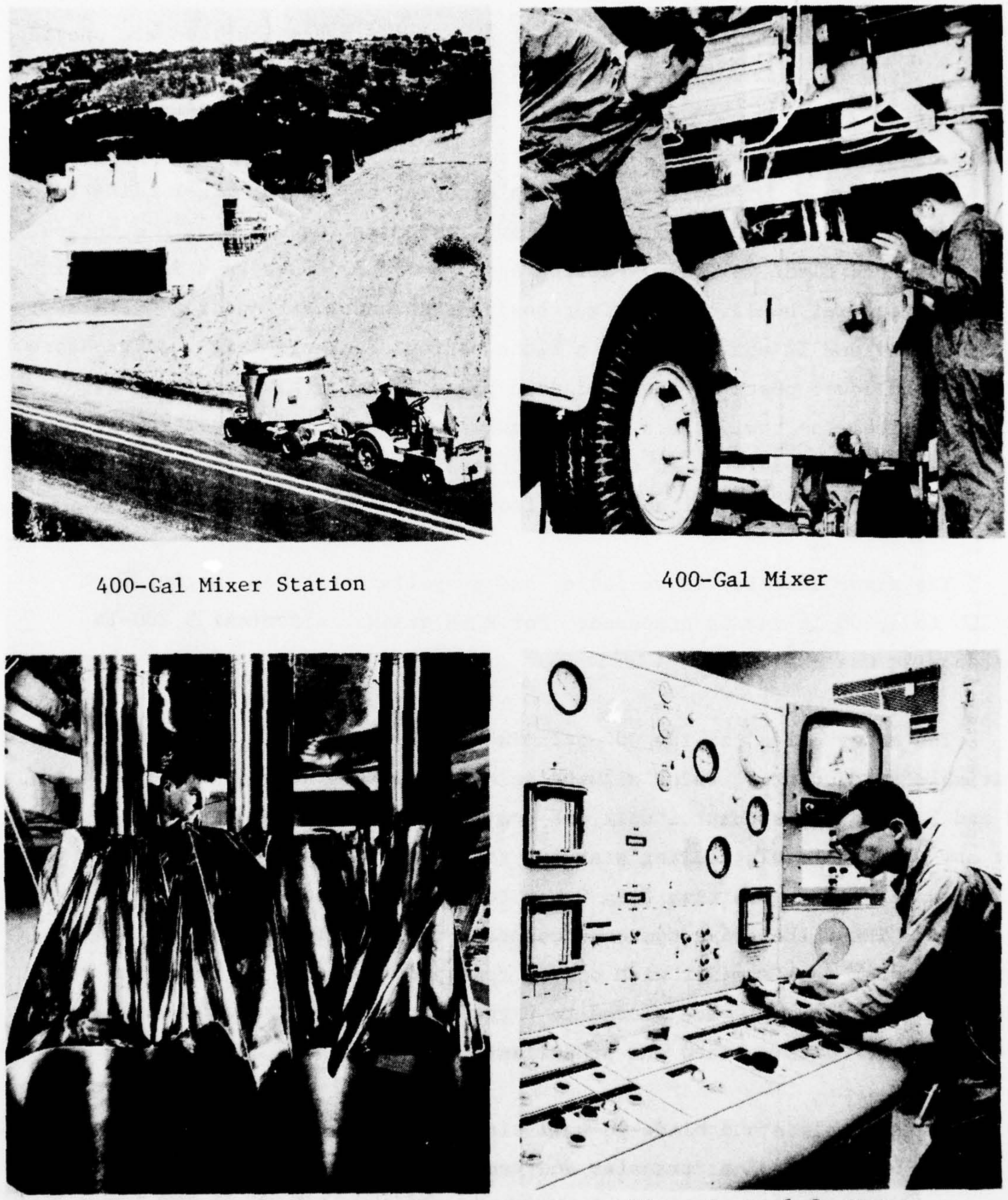
4.2.3.8.1 400-Gallon Mixer

All mixing of UTP-18,803A was completed in the 400-gal mixer illustrated in figure 37. The 400-gal mixer is a vertical mixer equipped with a three-paddle-shaped blade, planetary-action agitator, and is designed for use with changeable mixer bowls. Each mixer bowl has an undercarriage for over-the-road towing and is equipped with a flush bottom discharge valve. A pressure lid and follower plate are installed on the mix bowl; this permits casting directly from the bowl. This change-bowl technique permits short cycle times, eliminates the need for both fuel and propellant transfer cars, and eliminates cleaning of the mixer bowl and valve from the mixing operation.

The mixer capacity is variable, and propellant batches ranging from 1,200 to 5,600 lb may be prepared. For ELSH grains, a nominal 5,200-lb batch size was used.

The motor drive for the 400-gal mixer is equipped with an infinitely variable speed control which allowed selection of any desired speed between 0 and 24 rpm. This control unit can control blade speed with variable power at any desired level. During startup, the blades are slowly accelerated to the desired speed, starting from 0 rpm to that speed specified by manual control. Thus, the drive system encounters the same minimum shock loading on startup as does a mixer with only a few speed ranges. During mixer shutdown, the blades again are slowed to 0 rpm by manual control. A wattmeter records power density into the propellant.

Blade-to-blade and blade-to-wall clearance in the 400-gal mixer is 0.250 to 0.400 in. Heat transfer and temperature control in the 400-gal mixer are good. During operations, a jacket water temperature about 5°F lower than batch temperature is needed to maintain a constant batch temperature.



400-Gal Mixer Station

400-Gal Mixer

400-Gal Mixer Stainless Steel Blades

Mixer Control Center

Figure 37. 400-Gal Planetary Mixer

The small blade clearance and small temperature differential greatly reduce the possibility of unmixed propellant adhering to the mixer bowl wall.

4.2.3.8.2 Mix Procedure

The mix procedure for UTP-18,803A is outlined in table 25 and described below.

UTP-18,803A propellant mixing operations include (1) preparing the oxidizer, (2) preparing the fuel, and (3) mixing the oxidizer, fuel, and curative together to make propellant. The process flow diagram for mixing UTP-18,803A is given in figure 38. The nominal composition of UTP-18,803A is shown in table 2.

Before loading the ELSH cartridges, which required nine propellant batches for two grains, fuel premix (R-45M, HX-752, PRO-TECH®, Al) was made in master batches in a premix facility separate and removed from the propellant mix station.

Several distinct advantages arise from the use of large master batches of fuel premix:

A. Improved batch-to-batch uniformity and reproducibility. For example, a typical 5,000 lb propellant batch will contain 1,525 lb of fuel and be weighed to an accuracy of 0.5 lb. This is a potential variation of 0.03% and, since the BDR-45M is one-fifth of the fuel, the variation in NCO/OH is 0.0002. Subscale data presented in figure 39 show that the effect of NCO/OH ratio on propellant tensile strength is 830 psi/equivalent. Consequently, the effect of a ± 0.5 lb weighing variation will produce a variation in tensile strength of 0.2 psi (830 psi/equivalent x 0.0002 = 0.2 psi).
B. Less time to charge the propellant mixer. This results in significantly reduced turnaround times between batches (3 versus 9 hr) and a shorter time for loading the cartridge (15 versus 45 hr).
C. Overall improvement of efficiency from a reduced number of individual weighings, QC analyses, and manually-controlled mixing operations.

TABLE 25. 400-GAL MIX PROCEDURE FOR HTPB PROPELLANTS

T0427R

Operation	Jacket Temperature, °F	Blade Speed, RPM	Mix Time, min	Pressure, mm Hg	Propellant Temperature, °F
Add premix C to mix bowl (R45M, IDP, HX752, PRO-TECH® and Al)	145	-	-	Atmosphere	-
Add AP to mix bowl	145	12	30	Atmosphere	90 to 140
Vacuum mix	145	12	30	10	140±10
Scrape down; take QA sample; add IPDI	120 to 150	-	-	Atmosphere	140±10
Vacuum mix	120 to 150	12	30	10	140±10
Shut down; take QA sample	120 to 150	-	-	Atmosphere	140±10

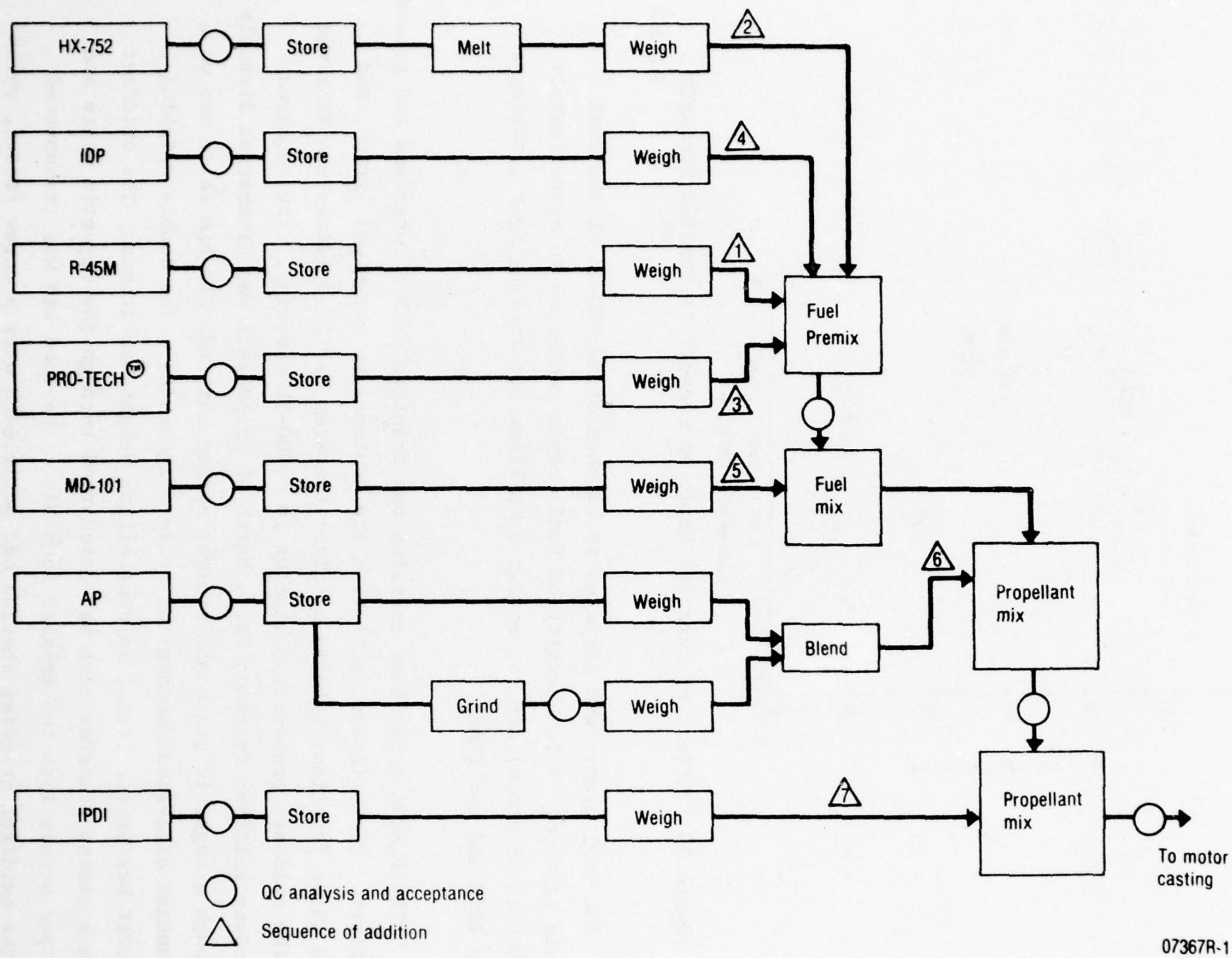


Figure 38. Process Flow Diagram for UTP-18,803A Propellant

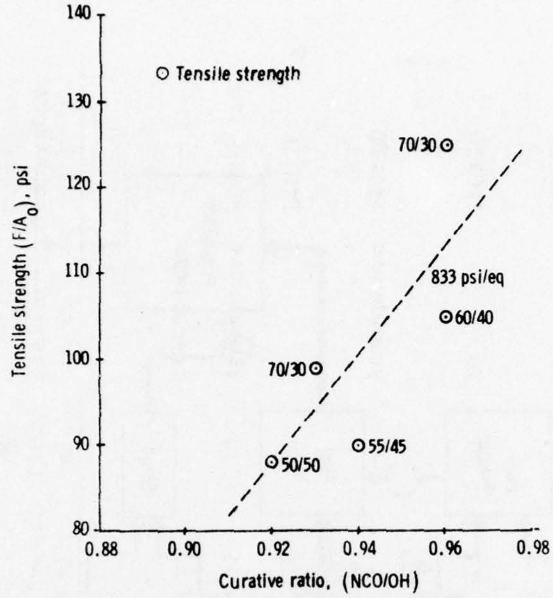


Figure 39. Effect of Curative Ratio on Propellant Tensile Strength

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The fuel premix was prepared in batches of 30,000 lb at the fuel premix station. This quantity of fuel premix converted to approximately 98,000 lb of propellant, or enough propellant for loading four cartridges (two ELSH and two CHAR).

UTP-18,803A propellant contains one fraction each of unground and ground oxidizer. The oxidizer facilities are designed to weigh out, grind, and load these fractions into an oxidizer transfer cart. Oxidizer was received at the oxidizer preparation station in 5,000-lb flo-bins. The required unground oxidizer fraction for a batch of propellant was discharged directly through a magnetic grate and scalper screen into the flo-bin which was on a redundant electrical/mechanical scale (figure 40). The double weighing concept has proven itself in controlling weight variations. The oxidizer from a second transfer cart was discharged through the magnetic grate and scalper screen into the grinder feed bin. The feed bin was transported to the oxidizer grinding station and positioned over a screw feeder, which fed the grinder at a controlled rate. The grinder, a Raymond Hammer mill,

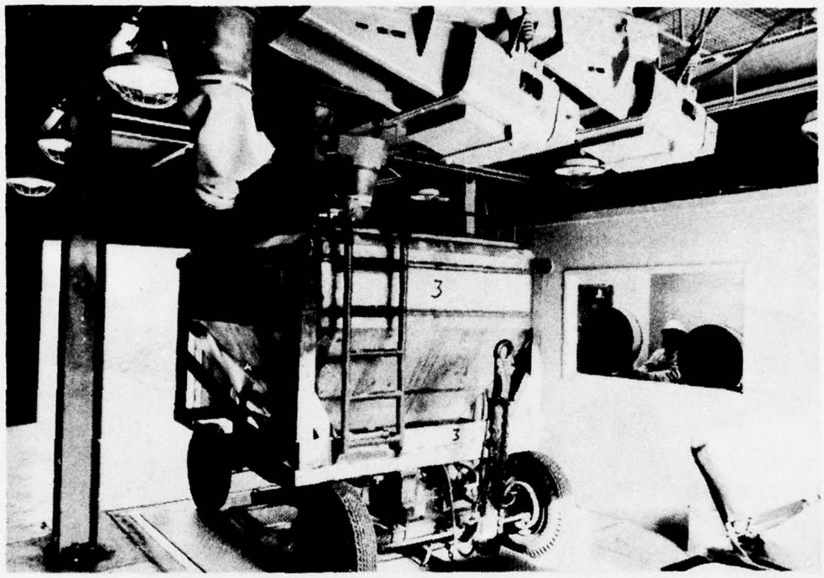

Figure 40. Oxidizer Weighing Station

yielded reproducible particles to the desired size of 9.5μ. This was achieved by using a predetermined hammer configuration, controlled hammer speed, and feed rate. This mill has a grinding capacity of 2,000 lb/hr and is illustrated in figure 41.

QC acceptance samples of ground and unground oxidizer were taken to ensure conformance to particle size and moisture standards.

The ground oxidizer was discharged directly from the mill into a flow-bin containing the preweighted unground oxidizer and resting on an electronic weight scale. The increase in weight was continuously monitored as ground oxidizer was added to the flow-bin until the correct weight of the ground oxidizer had been obtained. The correct weight was verified under static conditions by redundant weighings on the electronic and mechanical scales. The weights were recorded and verified by QC in accordance with mandatory procedures to assure that the correct weight of each oxidizer function had been added to the flo-bin and that the correct ratio of ground to unground oxidizer had been prepared.

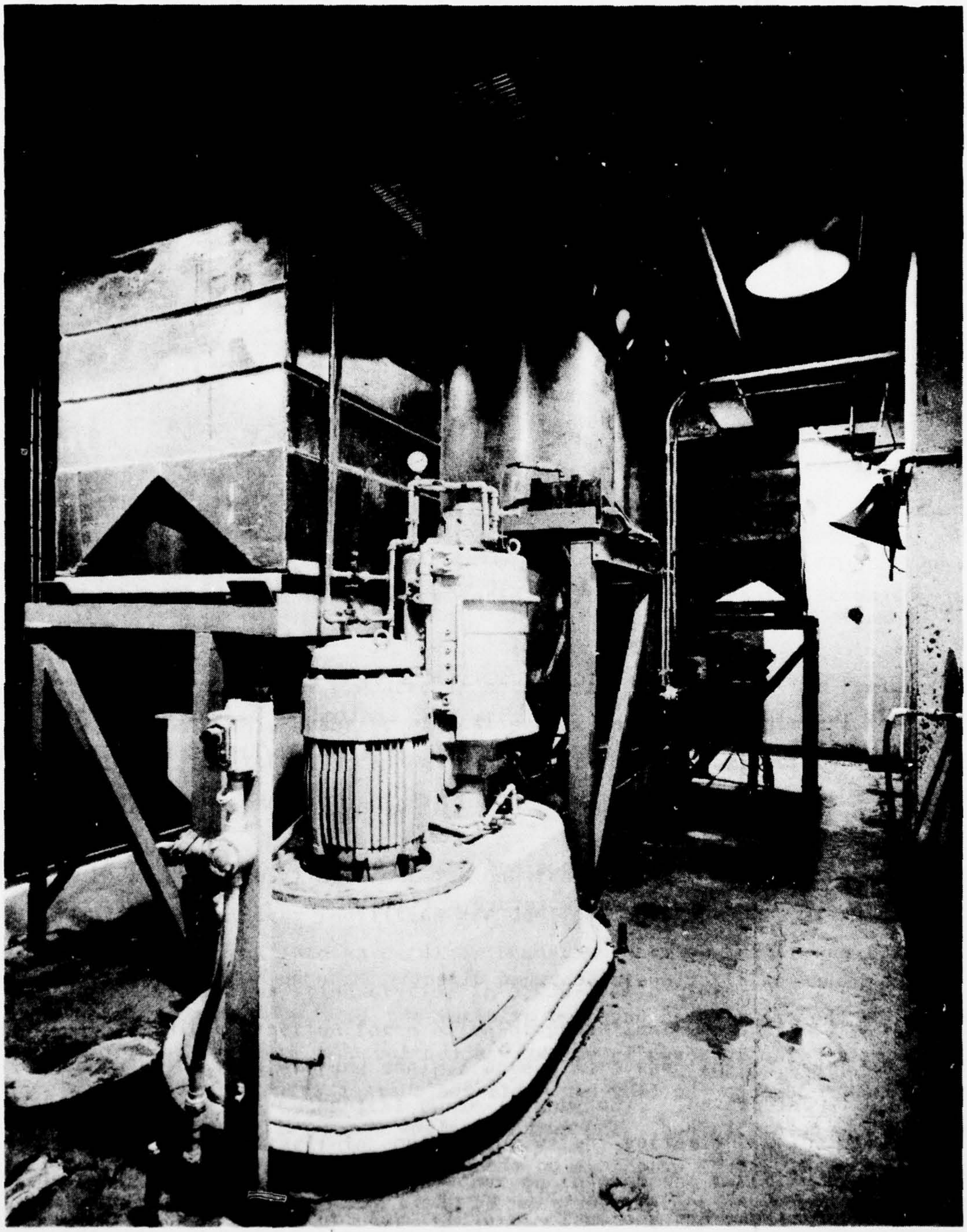

Figure 41. Oxidizer Grinders

The oxidizer was then transferred to an oxidizer cart for transport and subsequent addition to the propellant mixer (figure 42).

Fuel premix preparation consisted of the following operations:

A. IDP plasticizer was weighted into a jacketed, heating mixing vessel equipped with an agitator and heated to approximately 160°F.

B. HX-752 was taken from the cold box storage (0°F) and warmed to 80° to 120°F to facilitate handling. (HX-752 is a solid glass or, in some instances, a solid crystalline mass at cold box storage conditions.) The HX-752 was weighed and added to the IDP. The two ingredients were mixed under moderately high shear conditions by using a Cowles-type agitator to obtain proper dispersion. A QC sample was taken to ensure correct composition.

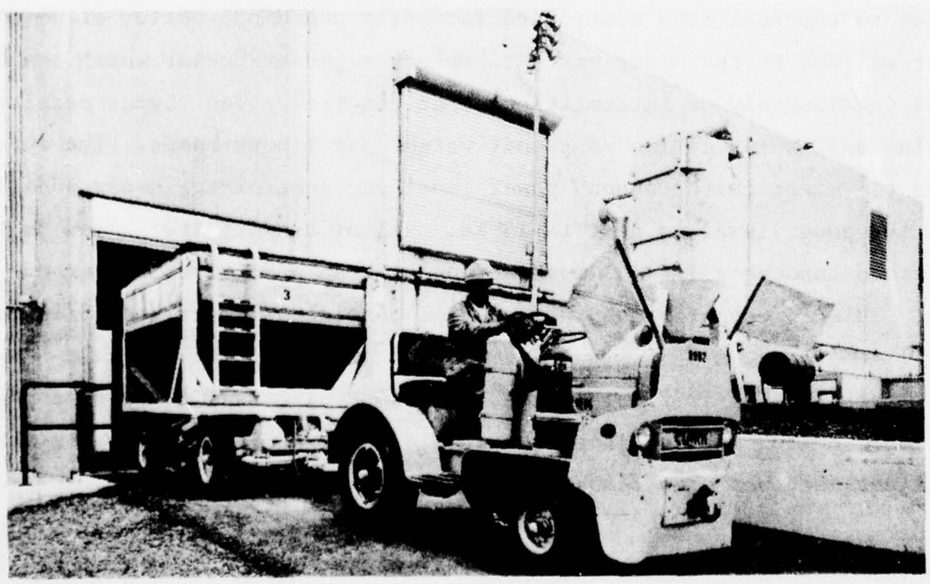

Figure 42. Oxidizer Transport

AD-A052 774 UNITED TECHNOLOGIES CORP SUNNYVALE CALIF CHEMICAL SY--ETC F/G 21/9.2
84-INCH PROPELLANT CARTRIDES AND GRAINS.(U)
NOV 77 T V O'HARA, J B HENRY, W A STEPHEN F04611-76-C-0010
UNCLASSIFIED CSD-2579-FR-VOL-1 AFRPL-TR-77-92-VOL-1 NL

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C. BDR-45M and PRO-TECH® 2705 were weighed and added to the primary fuel premix vessel followed by the IDP and HX-752 mixture. This vessel was equipped with an agitator of proper size to provide adequate dispersion of liquid fuels. A QC sample was analyzed to verify composition.

D. Aluminum powder was weighed, added, and mixed by means of agitation into the liquid fuels. After adequate mixing of aluminum and liquid fuels, a sample was taken and analyzed to assure conformance to acceptable standards. To maintain a uniform composition, the completed premix being used for propellant batches was stirred continuously to prevent setting of the aluminum.

E. Aliquot portions of the fuel premix master batch were weighed and added to the mix bowl at the fuel mixing station and transported to the mixer station. The bowl was preheated and the jacket filled with hot water.

The bowl was raised to the mix position, water jacket circulation lines attached, and the oxidizer cart positioned over the screener-feeder. Oxidizer was added to the fuel at a controlled rate over a nominal period of 30 min. Oxidizer was fed to the mixer via a vibratory screener-feeder which can be operated continuously or intermittantly, as required. The feeder permits controlled oxidizer addition on a unit weight per minute basis. The operator monitors the mixer instantaneous power level and controls oxidizer addition so that the power level is next to 15 kW. All of the oxidizer added to the mixer passed through a 1/4-in. mesh screen with an effective opening of 3/16-in. This screen prevents the entry of particles larger than 3/16 in.

A mixer blade of 12 rpm was used, and 140°F water was circulated through the jacket. Mixing was continued for 10 min after addition of the oxidizer. The oxidizer cart was then removed and the addition port closed.

Oxidizer addition was completed by vacuum mixing for 60 min at an absolute pressure of less than 10 mm Hg, with a blade speed of 12 rpm, and

at a temperature of 145°F. After vacuum mixing, the bowl was lowered, and the blades and upper part of the bowl were scraped down.

A QC sample was taken at this point to verify solids content and LSBR.

Curative was added, the bowl raised, the blades set in motion to 12 rpm, and mixing continued at an absolute pressure of 10 mm Hg at a temperature of 145° ± 5°F for 30 min.

Following completion of the vacuum mix cycle, the bowl was lowered and QC samples taken to verify curative content, solids content, and LSBR. The bowl was covered and transported to the casting station where propellant was removed for casting the necessary samples (e.g., 4-lb motor, BATES motors). The follower plate and pressure lid were then installed. The mix station was readied for the next batch propellant.

Propellant casting proceeded upon verification of QC test results.

4.2.3.8.3 QC and Acceptance Criteria

QC inspections/test and associated acceptance criteria are summarized in table 26.

Detailed process sampling procedures are defined by existing QC laboratory procedure QC K400 to ensure that samples taken from materials, premixes, or final mixes are truly representative of the material being tested and to ensure that this material is being handled properly to provide meaningful test results.

4.2.3.9 Casting and Curing of UTP-18,803A Propellant

4.2.3.9.1 Procedure

The propellant mix bowl was received at the casting station and the bowl connected to the casting line which is attached to the casting manifold in the oven (figure 43). After the QC laboratory notified the casting personnel that the batch was acceptable, the casting valve was opened and the batch cast into the preheated cartridge. A vacuum of approximately

TABLE 26. QC AND ACCEPTANCE CRITERIA FOR UTP-18,803A

Level of Inspection	Inspection: Inspection/Test	Inspection: Reason for Inspection/Test	Acceptance Criteria QC Procedures	Action to be Taken if Not per Specification
Ingredient				
BDR-45M	GPC/IR H_2O	Analysis performed before use to detect any storage or aging phenomena	QC-L585	Degas to bring within limits
AP	H_2O Particle size	Routine surveillance and assurance that material is still processable	QC-K522 QC-L504	Reject if caking problems could exist Determine suitable AP balance for batch
IPDI	NCO Dimer GPC/IR	Analysis before use to detect formation of dimer and obtain formulation information	QC-J703	NCO out of specification - scrap Dimer out of specification - scrap
Premix A: (HX-752 + IDP) + BDR - 45m + PRO-TECH® 2705)	HX-752	Process control point; imine content is essential in obtaining desired physical properties	TBS	HX-752 out of specification - scrap
	H_2O	Water interferes with the curing reaction	QC-K522	Degas to bring within limits
	GPC/IR	Comparison analysis (an in-process control)	TBS	
Premix B: (Premix A + Al)		N/A	N/A	
Premix C: (Premix B + AP)	AP Al GPC/IR LSBR	Verification Verification Comparison analysis Batch check before curative addition	TBS - - TBS	% AP, % Al, total solids; add curative and continue resample after curative
Propellant mix: (Premix C + IPDI)	LSBR AP Al IPDI GPC/IR	For ballistic evaluation over pressure range Verification (acceptance) Verification (acceptance) Verification of correct IPDI addition Comparison analysis	TBS - - - -	LSBR - add additional catalyst or scrap if LSBR too high LSBR - in-process check (outside single batch limits - scrap) Check % AP and Al - if still out (see premix D) High AP - scrap; low AP - check LSBR: Add AP if possible % IPDI low - calculate and add; high - scrap
Cured propellant	Tensile True stress Density Peel Bits Cured strands Stress endurance	Specification requirements (acceptance)	QC-N603 QC-N602 QC-N602 QC-N605 QC-N608 QC-N606	MRB action

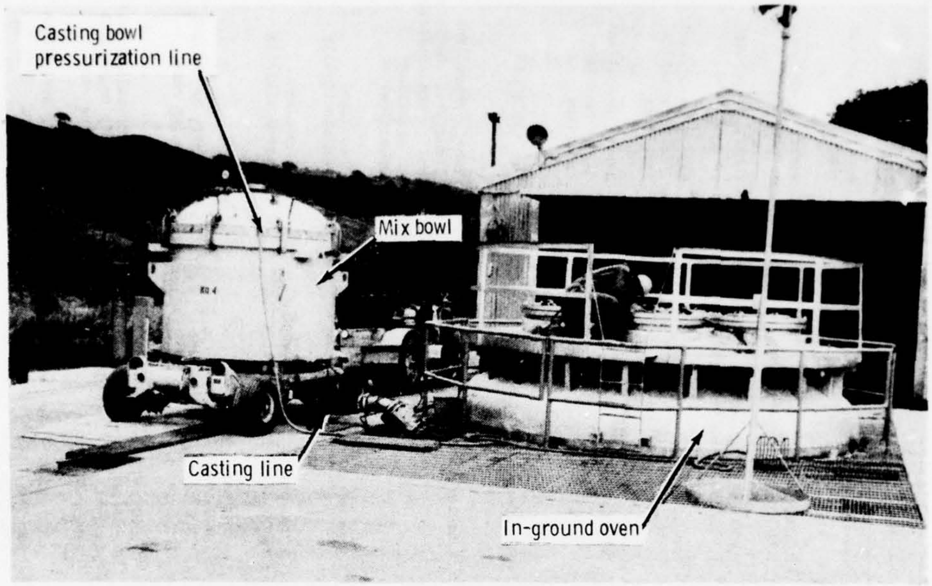

Figure 43. Medium In-Ground Ovens

35 mm of Hg was maintained in the chamber during casting to minimize entrapment of gases in the propellant.

At completion of the vacuum casting operation (i.e., after approximately 4.5 batches), the propellant was trowelled to height as specified on the fabrication drawing (C11479) with a minor quantity of propellant removed or added as required to meet drawing requirements. The cartridge was cured for 10 days at 140° ± 10°F. At completion of the cure cycle, the cartridge was cooled for a minimum of 24 hr at ambient conditions before stripping operations. The propellant samples cast for this program are summarized in table 27.

4.2.3.9.2 QC and Acceptance Criteria

The propellant sample cartons, peel trays, and BIT samples were sent to the laboratory for testing (table 26). QC monitored the cure cycle records to assure that procedure/specification requirements were satisfied.

TABLE 27. SAMPLING PLAN FOR PRODUCTION MIXES

	Item to be Cast	Cast In	When Cast	Property to be Measured	Method/Specimen	Test Matrix	Purpose of Test
In Process	Propellant samples		Each mix	Propellant composition	Laboratory analysis	See table 24	Verify propellant composition
			Each mix	Burning rate, precurative	LSBR	1,000 psi, 1,400 psi; Ambient temperature; 5 tests each pressure	Verify propellant burning rate
			Each mix	Burning rate, end of mix	LSBR	1,000 psi, 1,400 psi; Ambient temperature; 5 tests each pressure	Verify propellant burning rate
Cured Propellants	Test specimens	Propellant/liner/insulation	One set per cartridge		Bond-in-tension	Per QC-N608	Verify propellant/liner/insulation interface
		Propellant/liner/cartridge sample	One set per cartridge		Bond-in-tension	Per QC-N608	Verify propellant/liner/cartridge interface
			One set per cartridge		Peel specimen	Per QC-N605	See table 24
			Each mix	Uniaxial properties (tensile/true stress)	JANNAF class B	4 tests/batch -70°F	Verify propellant structural characteristics and conformance to propellant specification
		N/A	Each mix	Mix viscosity	Haake rheometer	1 hr after end of mix	Propellant reproducibility
		Carton	Each mix	Burning rate	CSBR	1,000 psi, 1,400 psi; 5 tests each pressure	Propellant reproducibility
	4-lb motors	Motor	Each mix	Burning rate	4-lb motor	800 psi, 1,000 psi, 1,400 psi, 1,650 psi; Ambient temperature; 1 test at each condition	Verify propellant burning rate
	15-lb BATES	Motor cartridge (GFE)	Each mix	Burning rate	15-lb BATES motors	1,000 psi, 1,400 psi, Ambient temperature; No. of tests selected by AFRPL	Motor scaling data; Verify propellant burning rate
	70-lb BATES	Motor cartridge (GFE)	Every second batch	Burning rate	70-lb BATES motors	1,000 psi, Ambient temperature; No. of tests selected by AFRPL	Verify propellant burning rate, k_n

4.2.3.10 Strip Casting Tooling and Trim Grain

4.2.3.10.1 Procedure

After a 10-day cure at 140°F and a 1-day cooldown, the loaded assembly was weighed to the nearest 0.1% to determine net propellant weight. The mandrel was removed by using a hydroset fixture at the in-ground ovens or the motor finishing station. The cartridge was removed from the casting base with the ELSH lift fixture and placed on supports, while the forward restrictor was inspected visually for separation and by audio testing for unbonds. The cartridge was then placed on the shipping pallet.

4.2.3.10.2 QC and Acceptance Criteria

Table 28 provides the QC inspection/test conducted on the loaded cartridge and identifies the associated acceptance criteria.

4.2.3.11 Package and Ship

A shipping pallet designed in accordance with the basic requirements of the code of federal regulations of DOT was made by CSD on contract No. F04611-73-C-0023. The pallet design and method of tiedown has been approved by the Bureau of Explosives and has been assigned a permanent approval number (BA-1845, marked on the shipping pallet). The pallet is compatible with the SLSH loaded cartridge.

The shipping pallet was provided as GFE with each GFE cartridge. The shipping pallet was constructed as shown in figure 44 to accept the cartridge grain in the vertical attitude and is secured to the pallet by four tie-down assemblies. The open end of the cartridge was closed by using a one-piece cover of electrostatic free (electroconductive) barrier material, 4-mil thick, which was taped to the OD of the cartridge to form a waterproof closure. A plywood shipping closure was placed onto the top of the cartridge and secured in place by using tension steel strapping attached to the pallet.

The palletized cartridge grains were loaded directly onto the carrier's equipment by using an overhead crane and the GFE lifting fixture.

TABLE 28. QC AND ACCEPTANCE CRITERIA FOR ELSH

T0429

Inspection/Test	Reason for Inspection/Test	Acceptance Criteria: Limits	Acceptance Criteria: CSD Procedure	Correction Action If Out of Specification
Inspect all visible surfaces for separations/unbonds	Acceptance per B/P	None allowed	O&QR	Fill with A1-227-70
Inspect all propellant surfaces for cracks and voids	Acceptance per B/P	Per B/P	O&QR	Submit to MRB
Dimensionally inspect grain:	Acceptance per B/P			Submit to MRB
length		Per B/P	O&QR	
bore		Per B/P	O&QR	
roundness		Per B/P	O&QR	
Workmanship: Free of defects which could affect function	Acceptance per B/P	None allowed	O&QR	Submit to MRB
Weight to 0.1%	Determine net propellant weight	Per B/P	O&QR	Submit to MRB
Audio inspect forward restrictors for unbonds and separations at edges	Acceptance per B/P	Per B/P	O&QR	Submit to MRB

4.2.4 Loaded Cartridge X-Ray

Under contract No. F04611-76-C-0010, CSD was required to x-ray inspect two loaded ELSH cartridges which were cast with UTP-18,803A. These cartridges were selected at random by the PCO to avoid a bias selection of only the best cartridge.

The cartridges subjected to x-ray were identified as P/N C11479-01-01, S/N 2579-01 and P/N C11479-03-01, S/N 2579-16. All x-ray inspection was conducted at the U.S. Naval Weapons Station at Concord, California (appendix K), under the supervision of CSD QC personnel. The two loaded cartridges were

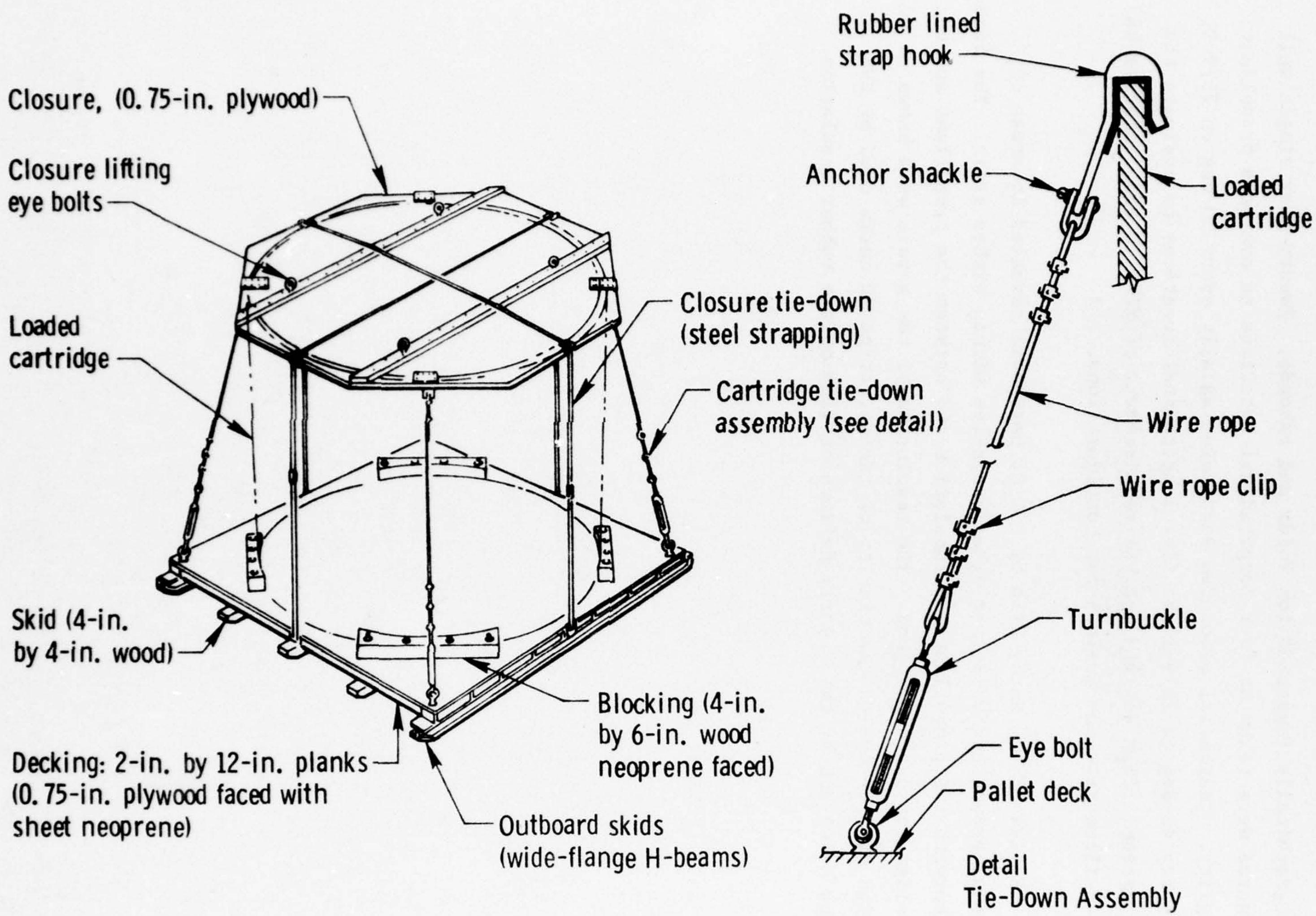

Figure 44. Shipping Base Assembly for Loaded Cartridge

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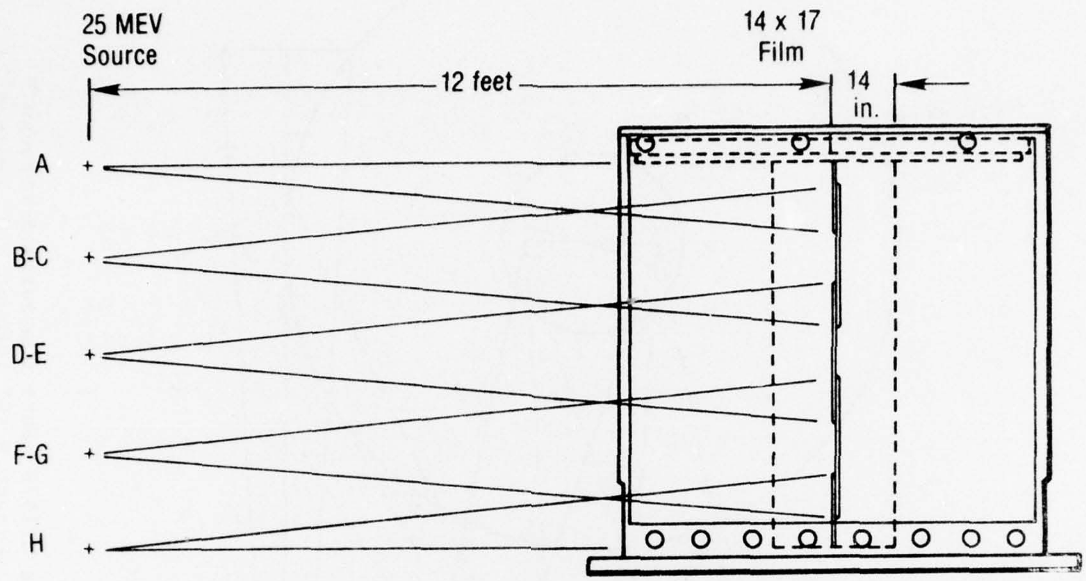
radiographically inspected for voids and unbonds. Twenty-four single wall exposures were taken at four longitudinal locations to evaluate propellant integrity. Tangential exposures were taken axially every 30 deg on 2579-01 and every 45-deg on 2579-16 at five longitudinal locations to evaluate the bond system. Film quality met the requirements of MIL-STD-453. Figures 45 and 46 illustrate the grain x-ray configurations.

Review of the x-ray film by CSD QC personnel revealed no areas of debonds, propellant voids, or other anomalies within either grain. The bonding between the propellant and insulation and between the propellant and the cartridge was extremely good. The resolution of the x-rays were known to be of high quality due to the clarity of the cartridge ID marks used by NWS during x-ray and by the clearly defined outline of the rubber insulation.

CSD ELSH Propellant Loaded Cartridge C11479
Bore Exposures A through H 0^0 through 350^0 Every 15^0



CSD ELSH Propellant Loaded Cartridge C11479
Tangent Line Exposures A through H 0^0 through 330^0 Every 45^0

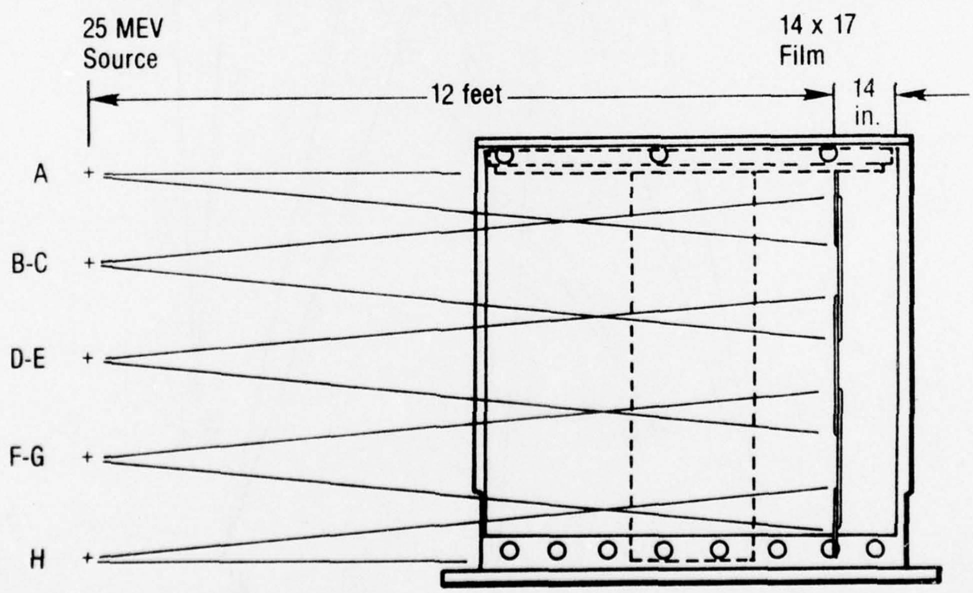


Figure 45. ELSH Loaded Cartridge X-Ray Configuration

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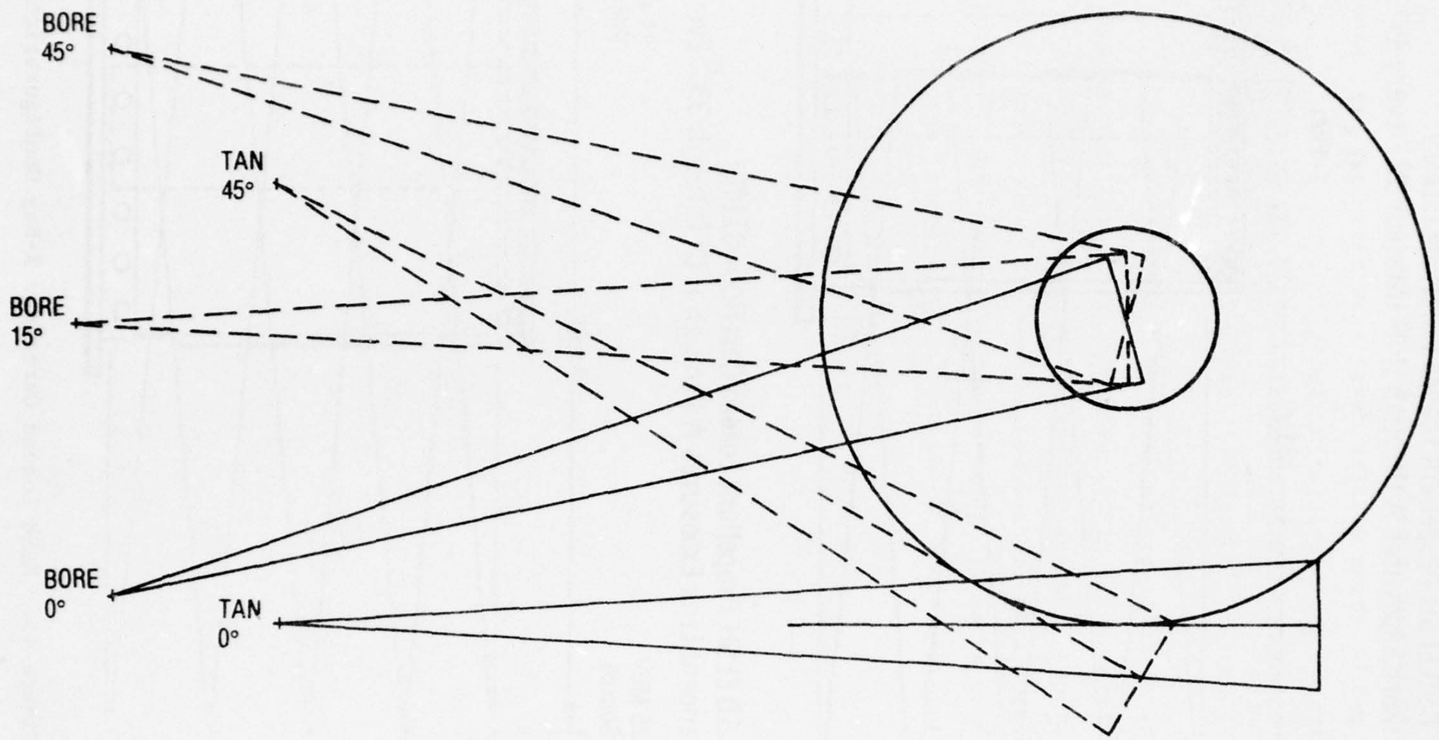

Figure 46. CSD ELSH Propellant Loaded Cartridge C11479, Bore Exposures A through H (0° through 345° Every 15°), Tangent Exposures A through H (0° through 330° Every 45°)

12656

4.3 PHASE III — DESIGN REQUIREMENTS, 84-IN. CHAR

The contract SOW specified the propellant ballistic requirements which established the grain design parameters for the 84-in. CHAR grains. The test motor configuration is shown in figure 47.

4.3.1 Design Criteria

4.3.1.1 Propellant Selection

The propellant used in the casting of the 84-in. CHAR propellant grains was UTP-18,803A, the same 90% solids, 21% aluminized, HTPB propellant used for casting the ELSH grains (sections 4.1 and 4.2).

4.3.1.2 Motor Ballistics

The 84-in. CHAR grains were designed to produce a nominal chamber pressure of 1,000 psi ± 5% with a 7-in.-diameter throat (assuming an 80°F grain temperature). No throat erosion was assumed. Grain designs were required to yield nominal burning durations of 15 sec ± 1 sec, 30 sec ± 2 sec, and 60 sec ± 3 sec.

4.3.1.3 Cartridge Design

The GFE cartridge, which is very similar to the ELSH cartridge, is a fiberglass cloth/fiberglass Fabmatt/polyester resin cylinder. It is 82-in. long, has an OD of 77.8 in., and a wall thickness of 1.5 in. Like the ELSH cartridge, it is a pressure balanced cartridge. For an end burning grain, backside pressurization is achieved through six 1.3-in.-diameter holes at the aft end of the cartridge. These holes are also used to lift and handle the cartridge. The cartridge is sealed (to prevent flow after pressurization) aft of the holes with an O-ring installed in a metal ring which is part of the CHAR motor chamber wall. Backside pressurization occurs by venting gas around the forward end of the grain and cartridge and into the annulus. In this case, the lifting holes are sealed with rubber plugs after the cartridge is installed into the motor.

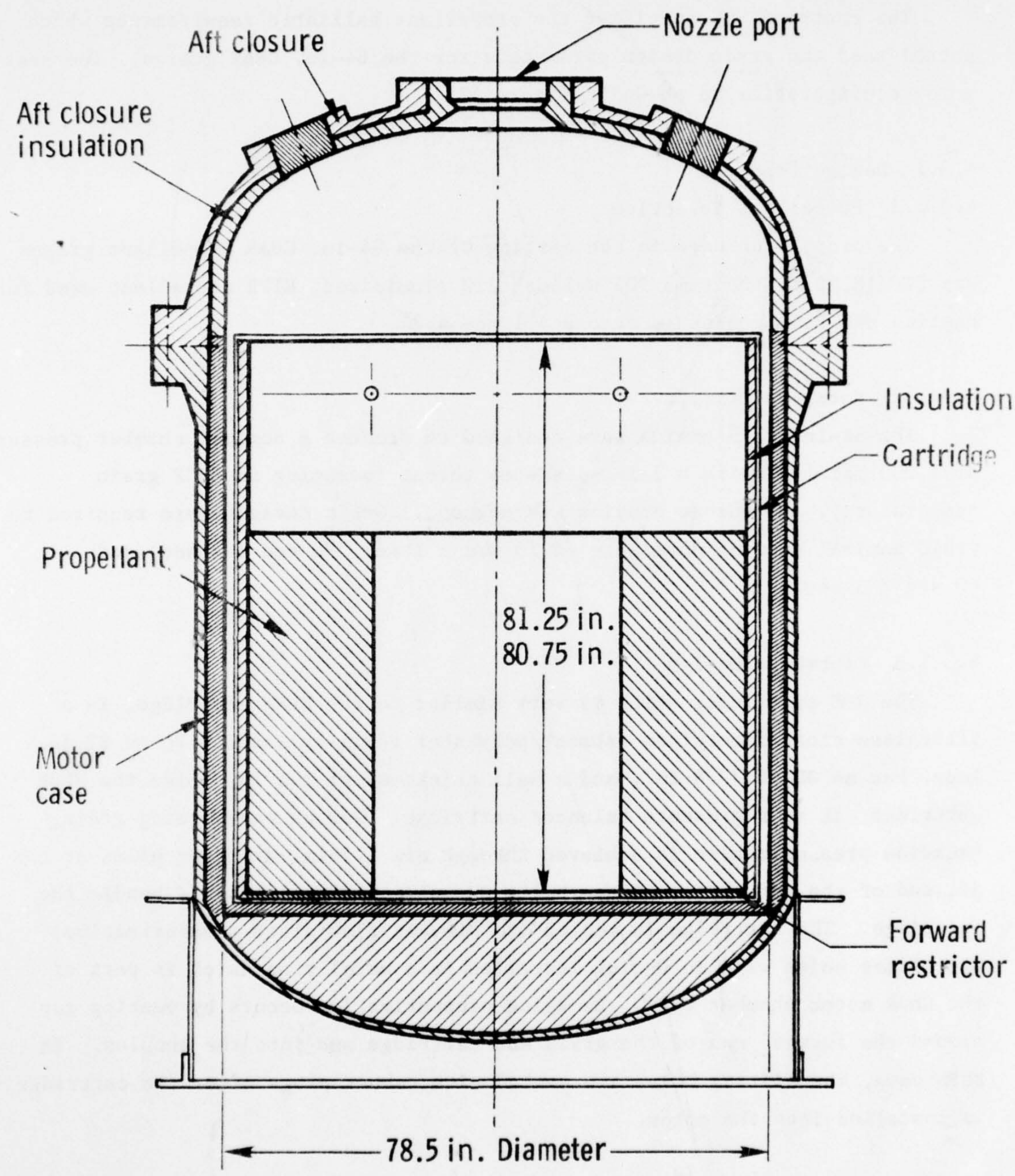

Figure 47. 84-in. CHAR Motor Test Configuration

4.3.1.4 Insulation System Design

The insulation design, material, and method of construction for the 84-in. CHAR motor met all requirements of the contract and were essentially the same as those successfully test fired in the 84-in. CHAR motor using a similar 90% solids-loaded HTPB propellant (UTP-16,905).

The insulation for the 60-sec grain consisted of 0.75-in.-thick silica-asbestos-filled buna-N rubber (ORCO-9250) extending 52 in. forward from the aft end of the cartridge. The previously tested design with 0.375-in.-thick insulation was adequate for the other two grain configurations (figure 48). Both designs included the 2.0 safety factor required by the contract. The vulcanized rubber was bonded to the cartridge interior with epoxy adhesive. Axial and circumferential butt joints (maximum gap of 0.10 in.) were filled with Hill-Gard V-61.

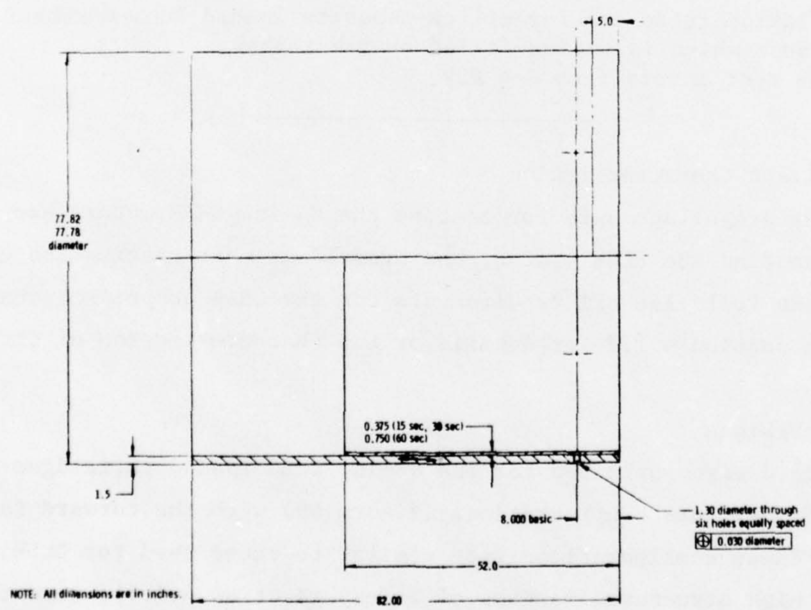

Figure 48. CHAR Motor Cartridge

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The ablation expected was computed for the radiation level similar to that for the ELSH cartridge, but at 1,000 psia, using data from table 29. Since the convective environment is negligible, the radiation-imposed ablation rate is 5.5 mils/sec, with a char depth of 0.03 in. below the surface. For the 63-sec test requirement, the total ablated depth is 0.38 in. including char penetration; for the total insulation, the thickness is 0.76 in. The present cartridge insulation is adequate for the other two grain designs.

TABLE 29. ABLATION DATA FOR FORWARD CLOSURE RUBBER

T0409

Motor	Chamber Pressure, psi	Aluminum, Wt-%	T_o, °R	Q_{rad}	a, mil/sec
Titan	574	16	5,999	4.28	1.5 to 2.0*
LS1†	778	18	6,309	5.23	2.31
LS2†	950	18	6,339	5.33	3.30
ELSH/Super HIPPO	1,500	21	6,775	6.98	5.70

* Average ablation rates are for silica-asbestos loaded Buna-N rubber except for Titan data which is silica-filled Buna-N rubber.
† Large-scale test motors from C-4 EDP.

4.3.2 Propellant Characterization

Since the propellant used for casting the 84-in. CHAR motors was the same as used for casting the ELSH grains, the propellant characterization completed in phase I also fulfilled all requirements for the CHAR propellant characterization. See section 4.1.2 for details of the characterization of UTP-18,803A.

4.3.3 Grain Designs

The grain designs selected for the 84-in. CHAR loaded cartridges were simple cylindrical bore configurations (figure 49) with the forward face restricted. These configurations were similar to those used for ELSH; provided for high structural margins of safety (section 4.3.4); were the most cost effective to cast; and were similar to several grains which had been successfully demonstrated in 84-in. CHAR motor tests at AFRPL.

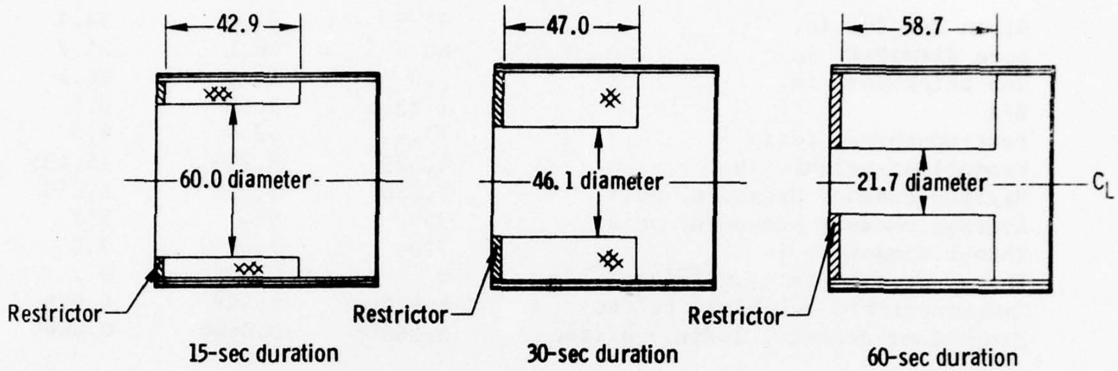

Figure 49. CHAR Motor Grain Configuration

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The three grain designs were developed using the criteria specified in the contract SOW (section 4.3.1). Table 30 summarizes the critical grain parameters. The predicted test duty cycles are shown in figures 50 through 52.

The characteristic velocity, c*, used in the grain designs accounted for the heat losses associated with the CHAR motor. A c* of 4,916 ft/sec was used to size the 84-in. CHAR motor grain. This value was calculated for an 84-in. CHAR motor test using a 90% solids HTPB propellant, UTP-16,905, similar to UTP-18,803A. The use of this measured c* was valid because of the small (0.17%) difference in the theoretical c*s of UTP-18,803A and UTP-16,905. In addition, the measured c* agreed within 0.1% of the value calculated from a heat loss analysis.

The forward restrictor on the three CHAR grain configurations was made by casting AL-60-9-2 potting compound to a thickness of 0.9 in. minimum and curing before casting the grain.

TABLE 30. UTP-18,803A GRAIN AND BALLISTIC DESIGN CHARACTERISTICS OF 84-IN. CHAR MOTOR

T0419R

	Nominal Duration		
Characteristic	15 sec	30 sec	60 sec
Grain length, in.	42.9	47.0	58.7
Bore diameter, in.	60	46.1	21.7
Web thickness, in.	7.0	13.9	26.1
B/A	1.23	1.60	3.4
Port-to-throat ratio	73.4	43.4	9.6
Propellant weight, lb	4,329	8,333	15,435
Maximum chamber pressure, psia	1,050	1,050	1,050
Average chamber pressure, psia	954	934	957
Throat diameter, in.	7.0	7.0	7.0
Throat erosion rate, mils/sec	0	0	0
Characteristic velocity, ft/sec	4,916	4,916	4,916
Propellant density, $lb/in.^3$ n./sec	0.0666	0.0666	0.0666

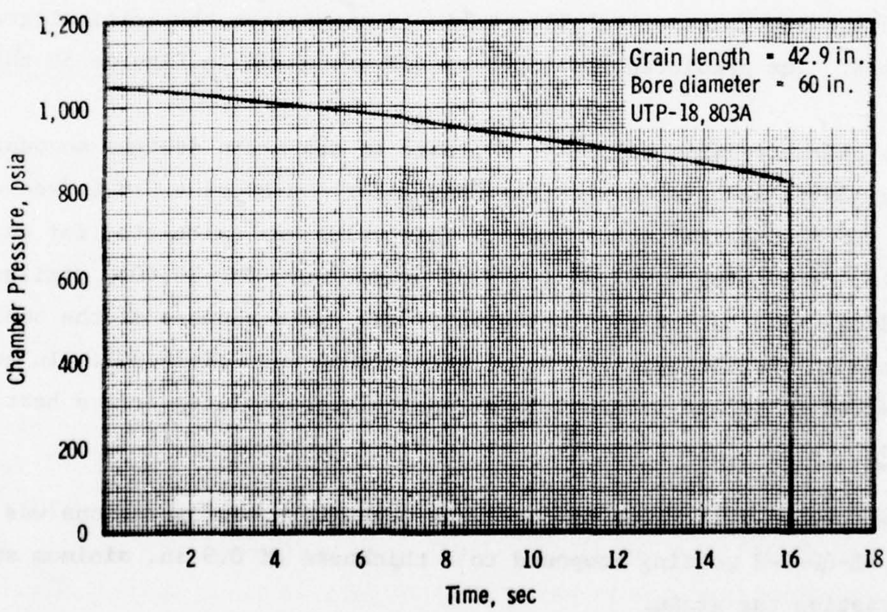

Figure 50. Chamber Pressure vs Time for 15-sec CHAR Motor

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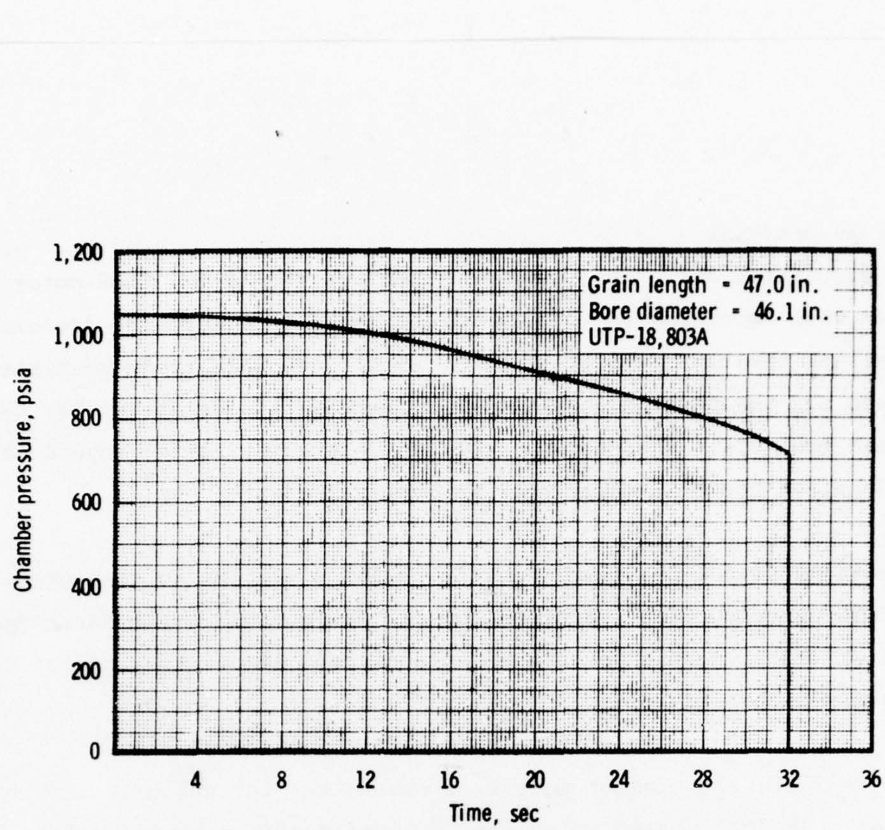

Figure 51. Chamber Pressure vs Time for 30-sec CHAR Motor
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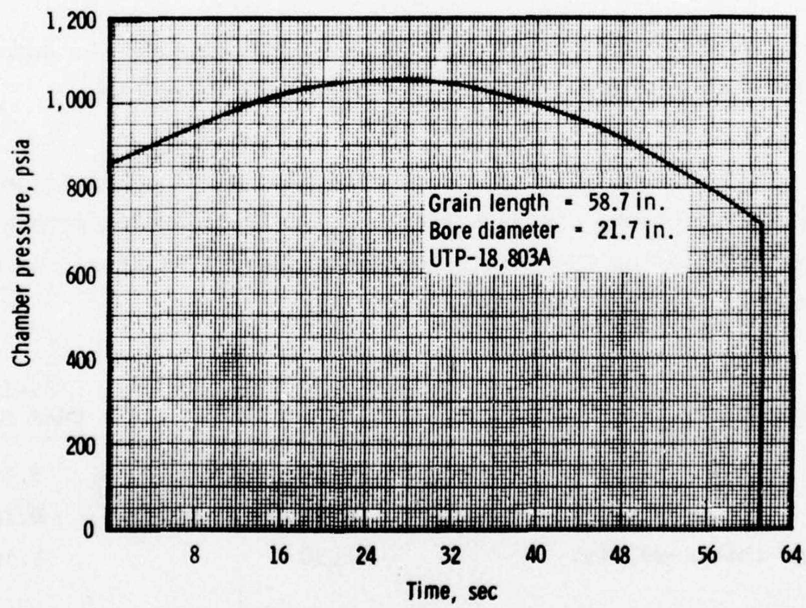

Figure 52. Chamber Pressure vs Time for 60-sec CHAR Motor
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4.3.4 Grain Analysis

The structural analysis procedures used for the 84-in. CHAR motor grain cartridges were identical to those used for the ELSH cartridges (section 4.1.4). The propellant material properties measured for the ELSH grain analysis encompassed all the physical properties data required for the 84-in. CHAR motor grain analysis. Therefore, propellant characterization beyond that already done for the ELSH cartridges was not necessary.

A two-dimensional quasiviscoelastic analysis similar to that performed for the ELSH cartridge was performed for the 84-in. CHAR motor cartridge. A summary of the principle failure modes and their associated margins of safety is given in table 31.

As with ELSH, the minimum margin of safety was for unbond at the bond termination. The calculated value was +0.11 after the required safety factor was applied to the calculated stress. The minimum margin of safety for bore strain was +0.72 after the required safety factor of 1.5 had been applied to the calculated value.

The model used for this analysis is shown in figure 53; the deformed profile of the grain under thermal loads is shown in figure 54.

Because of the similarity between the ELSH and 84-in. CHAR loaded cartridges, compared below, the data from the 1/5-scale analog motors were directly applicable to the CHAR grain configurations. Therefore, no analog motors were tested for the CHAR loaded cartridges.

Parameter	ELSH	84-in. CHAR Motor
B/A	3.24	3.44
L/D	0.96	0.78
Cartridge thickness, in.	1.50	1.50

TABLE 31. 84-IN. CHAR MOTOR CARTRIDGE-LOADED PROPELLANT GRAIN STRUCTURAL ANALYSIS

(1) Failure Mode	(2) Calculated (A) Stress/Strain, psi, %	(3) Minimum Specified Allowable Stress/Strain psi, %	(4) Reduced (B) Allowable for Variability and Aging Effects, psi, %	(5) Margin of Safety, (4)/(2) - 1
Failure modes due to storage for 2 yr between 60° and 80°F				
Unbond at grain termination due to combined shear and tension forces	15.1	20 (C)	16.7	0.11
Hoop strain failure in bore	3.9	8 (D)	6.7	0.72
Failure modes during transportation				
Unbond at grain termination from combined shear and tension forces due to cooldown to -20°F	30.2	60 (E)	50	0.66
Unbond at grain termination due to 2 g shock load	6.8	100 (F)	83	>10
Hoop strain failure in bore due to cooldown to -20°F	7.8	13 (E)	10.8	0.38
Unbond at grain termination due to cumulative damage effects of transportation				0.66 (G)
Failure modes due to pressurization (H)				
Unbond at grain termination due to deviatoric normal tension forces	82	200 (I)	167	1.49
Hoop strain failure in bore	10.7	20 (I)	16.7	0.56

(6) Notes

(A) Include the required safety factors of 2 on bondlines and 1.5 on the propellant.

(B) Allowables have been reduced by a factor of 1.2 to account for the effects of chemical aging. A batch-to-batch reduction factor of 1 is used, as the allowables are the specified minimums.

(C) Uniaxial endurance stress at 2 yr at 60°F is estimated to be the same as the uniaxial endurance stress at 1 yr at 70°F.

(D) Biaxial endurance strain at 2 yr at 60°F is estimated from the specified uniaxial endurance strain a 1 yr at 70°F.

(E) Appropriate endurance stress and strain values at -20°F at 1 day are estimated from the specified minimum properties.

(F) Standard rate JANNAF stress has been increased by a factor of 2 to account for the improvement due to high rate shock loadings.

(G) Cumulative damage margins of safety for combined loading conditions are computed as follows:

$$MS = FS_c - 1 \text{ where } \frac{1}{(FS_c)^a} = \frac{1}{(FS_1)^b} + \frac{1}{(FS_2)^c} + \ldots$$

and a,b,c, etc. are the relevant endurance curve slopes.

(H) The pressurization analysis is inherently conservative as it assumes pressure does does not occur between the case and cartridge. The cartridge thus deflects radially outward until it contacts the steel motor case.

(I) The standard rate JANNAF stress at 70°F has been increased by a factor of 4 to account for the effects of high strain rate improvement and pressure field enhancement. The JANNAF strain has not be increased for these effects.

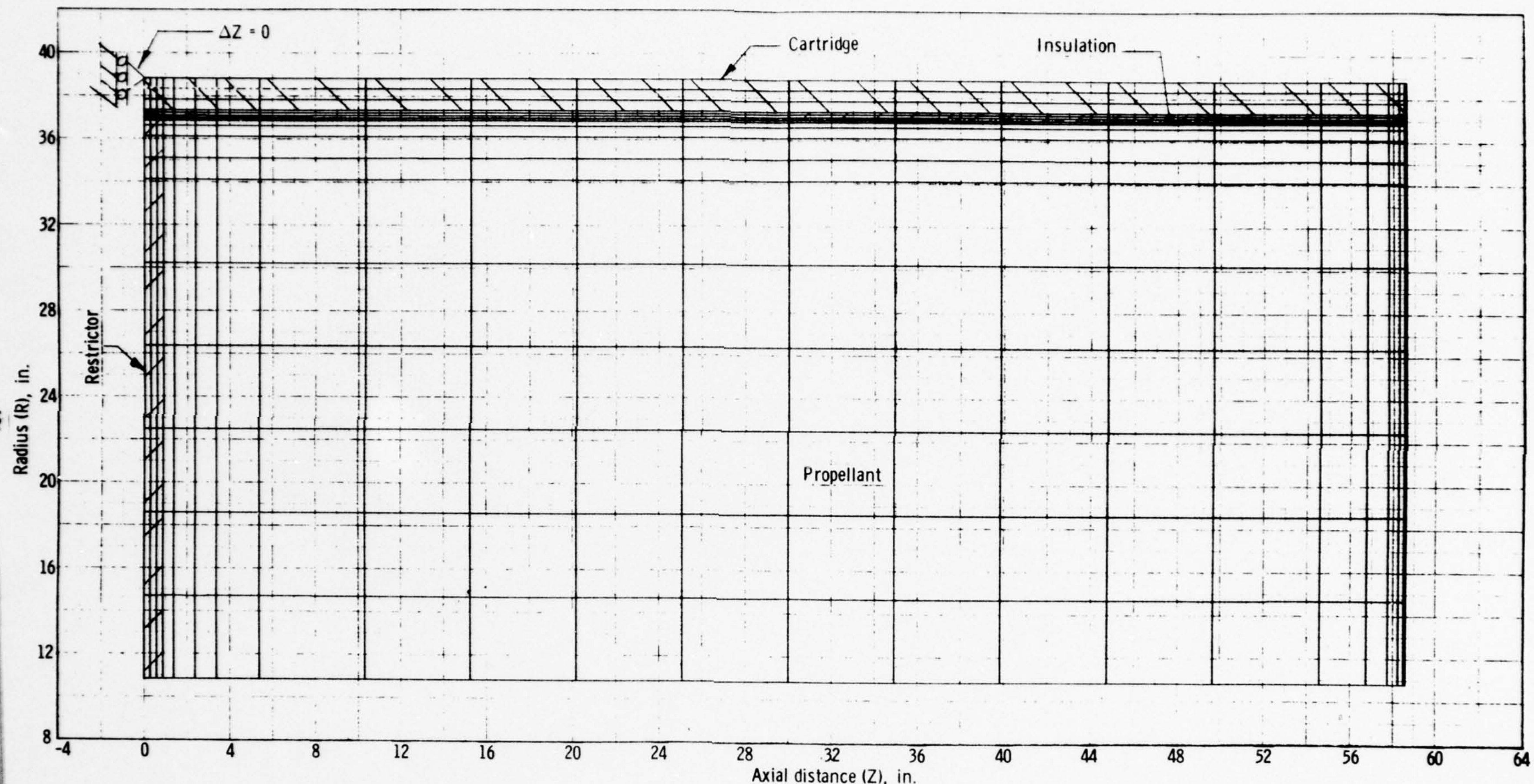


Figure 53. 84-in. CHAR Motor Cartridge Grain

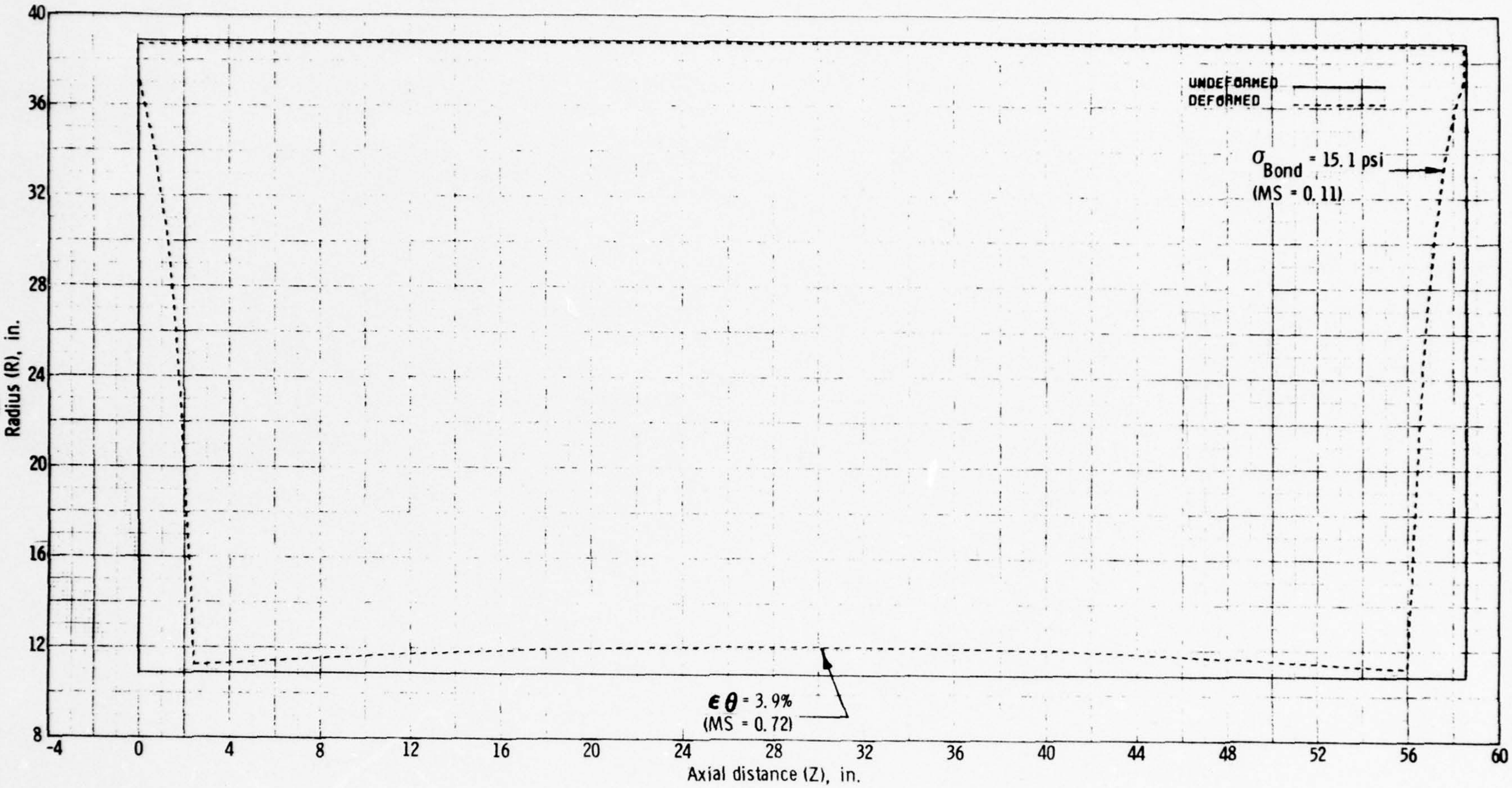


Figure 54. Deformed Grain for Cooldown to 60°F (Deformation Magnified by a Factor of Five for Clarity)

4.4 PHASE IV — PROPELLANT PROCESSING AND QA FOR CHAR GRAINS

Phase IV encompassed the casting of ten CHAR cartridges for delivery to AFRPL. The specific loaded CHAR cartridges delivered to AFRPL are itemized in table 32.

TABLE 32. DELIVERED CHAR GRAINS

Part No.	Serial No.	Cast Date	Nominal Test Duration, sec
C12185-01-01	2579-01	10 Apr 76	60
	2579-10	16 Sep 76	60
	2579-13	5 Oct 76	60
	2579-14	3 Aug 77	60
C12185-02-01	2579-06	23 Jul 76	30
	2579-08	12 Aug 76	30
	2579-12	16 Sep 76	30
C12185-03-01	2579-07	23 Jul 76	15
	2579-09	12 Aug 76	15
	2579-11	26 Aug 76	15

4.4.1 Summary

This section presents an overview of the propellant produced and the results of the propellant ballistic and mechanical property evaluations. The subject matter related to CHAR motor grains is largely identical to that covered in section 4.2 for the ELSH grains since the same propellant and processing techniques were used for both. Therefore, the propellant data will not, in general, be duplicated here; appropriate subsections in section 4.2.1 will be referenced as required.

4.4.1.1 Propellant Formulation

UTP-18,803A was used for casting both the ELSH and CHAR grains. Refer to section 4.2.1.1 for further details.

4.4.1.2 Batch Summary

Refer to section 4.2.1.2.

4.4.1.3 Ballistic Properties

Refer to section 4.2.1.3.

4.4.1.4 Physical Properties

Refer to section 4.2.1.4.

4.4.2 Casting Tooling Design and Fabrication

The CHAR casting tooling design is identified as P/N C12030. The tooling design is similar in detail to the ELSH tooling described in section 4.2.2.

4.4.3 Propellant Processing and QA

The discussion which follows describes the propellant processing procedures and the QA verifications used in casting the CHAR loaded cartridges. The processing specification for UTP-18,803A (SE0720) is presented in appendix C.

The O&QR and the IQOP for processing the CHAR cartridges are presented in appendix G.

The general propellant processing logic used in casting the CHAR cartridges is illustrated in figure 55. Detailed discussion of this approach, including the process steps and QA procedures, follows. In those instances where the processing of the CHAR cartridges is the same as for the ELSH cartridges, reference will be made to the proper subsection of section 4.2.3.

4.4.3.1 Materials Control

Refer to section 4.2.3.1.

4.4.3.2 Process Tooling

The process tooling for the CHAR cartridges was the similar to that used for ELSH. Therefore, the discussion presented in section 4.2.3.2 is applicable to CHAR and will not be repeated here.

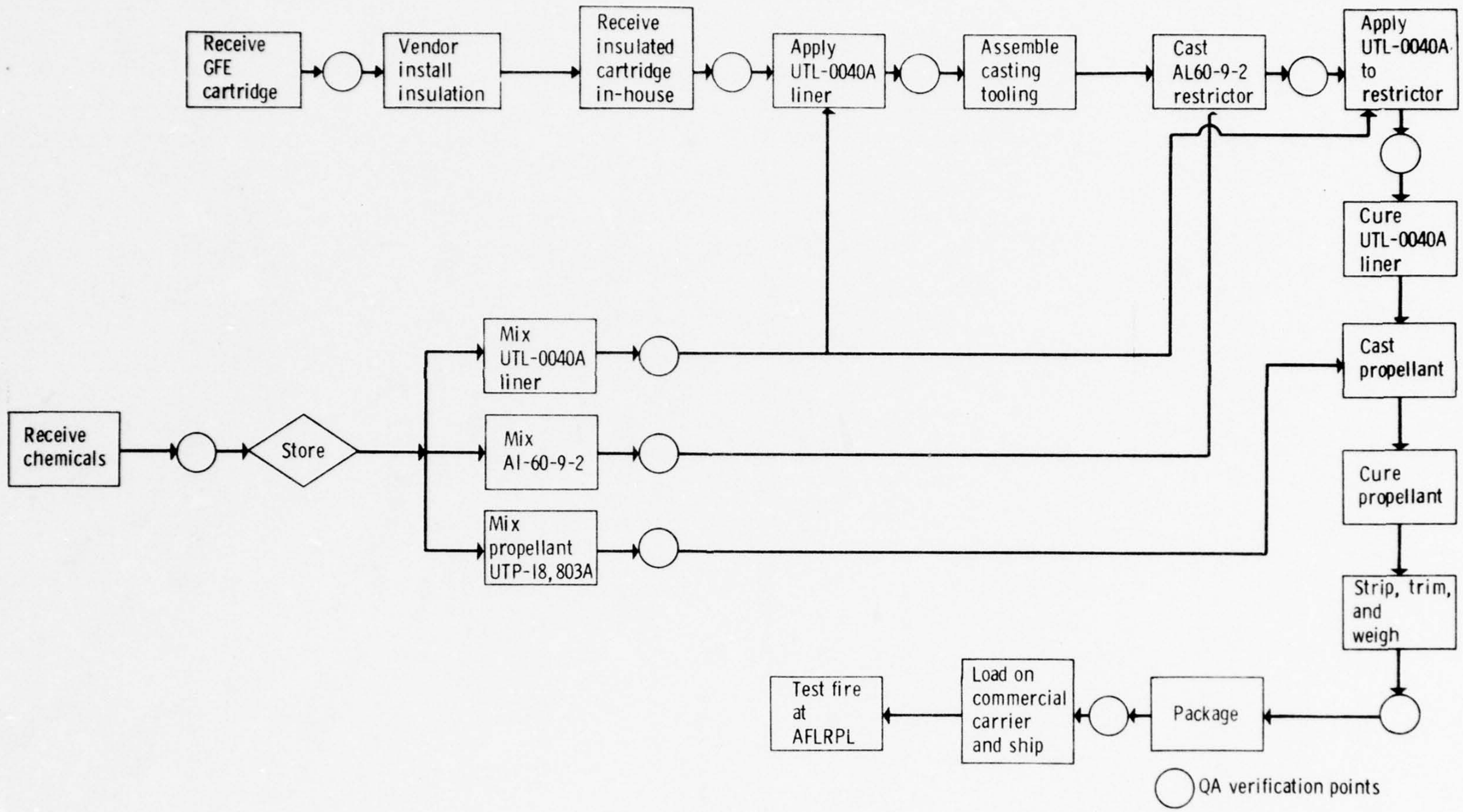


Figure 55. Process Flow Diagram for 84-in. Propellant Cartridges

4.4.3.3 Cartridge Insulation

As was the case with the ELSH cartridges, American Polytherm was selected by CSD to insulate the CHAR cartridges. In this instance, however, the vendor was responsible for installing only the sidewall insulation; CSD cast the forward restrictor.

4.4.3.3.1 Insulation of Cartridge Sidewall

A. Procedure

See section 4.2.3.3.1.

B. QC and Acceptance Criteria

See section 4.2.3.3.1.

4.4.3.3.2 Forward Restrictor Installation

A. Procedure

AL-60-9-2 liner was used to form the cast-in-place forward restrictor in the CHAR cartridge before lining and propellant casting. The nominal composition of AL-60-9-2 is as shown below:

Material	Wt-%
Versamid 125	66.7
ERL-2795	33.3

AL-60-9-2 was mixed in a 5-gal Ross mixer at ambient room temperature. Quantities of Versamid 125 and ERL-2795 were weighed and added to the mix bowl and mixed for 2 min at atmospheric pressure, and then mixed for 12 min under a vacuum of 28.5 in. of mercury or greater. A QC sample was taken and analyzed for resin content before use. Since AL-60-9-2 starts curing at room temperature, a substation of the QC laboratory was set up in the liner mixing room for analysis. The appropriate quantity of accepted AL-60-9-2 was poured to form a minimum of 0.9-in.-thick restrictor. The AL-60-9-2 was cured at 100° to 130°F for 16 hr.

B. QC and Acceptance Criteria

QC laboratory verification of the AL-60-9-2 formulation is to specification 4MDS-41402 according to QC laboratory procedure QC-N507. Verification of Versamid 125 content (minimum 58.29, maximum 71.40) and epoxy content (minimum 28.60, maximum 41.71) is provided for each mix of the AL-60-9-2. After cure, the restrictor is inspected for conformance to B/P requirements for thickness (0.9 in.).

4.4.3.4 Cartridge Preheat

Refer to section 4.2.3.4.

4.4.3.5 Liner Preparation

Refer to section 4.2.3.5.

4.4.3.6 Application of UTL-0040A Liner

Refer to section 4.2.3.6.

4.4.3.7 Assemble Casting Tooling

The CHAR casting tooling is identified as P/N C12030. The tooling assembly procedure is the same as for ELSH (section 4.2.3.7) except that the core sizes varied depending upon the configuration beings cast:

Nominal Test Duration, sec	Core Size, in.
60	21.7
30	46.1
15	60.0

4.4.3.8 Propellant Mixing

Refer to section 4.2.3.8.

4.4.3.9 Casting and Curing of UTP-18,803A Propellant

Refer to section 4.2.3.9.

4.4.3.10 **Strip Casting Tooling and Trim Grain**

Refer to section 4.2.3.10.

4.4.3.11 **Package and Ship**

Refer to section 4.2.3.11.

5.0 PROPELLANT REPRODUCIBILITY

This section presents a summary of the ballistic and mechanical property data obtained from UTP-18,803A from the series of 137 400-gal batches made in fulfillment of the contract requirements. Volume II of this report contains the specific test data which comprise these summaries.

5.1 BALLISTICS

The ballistic reproducibility of UTP-18,803A was shown to be better than that reported for Minuteman and comparable to that demonstrated on Titan and Algol. Figure 56 presents a plot of 4-lb motor test data from production run No. 1 illustrating the high degree of reproducibility demonstrated for UTP-18,803A. This section will summarize the ballistic characteristics in terms of 4-lb motor reproducibility, burning rate control, and motor scaleup effects.

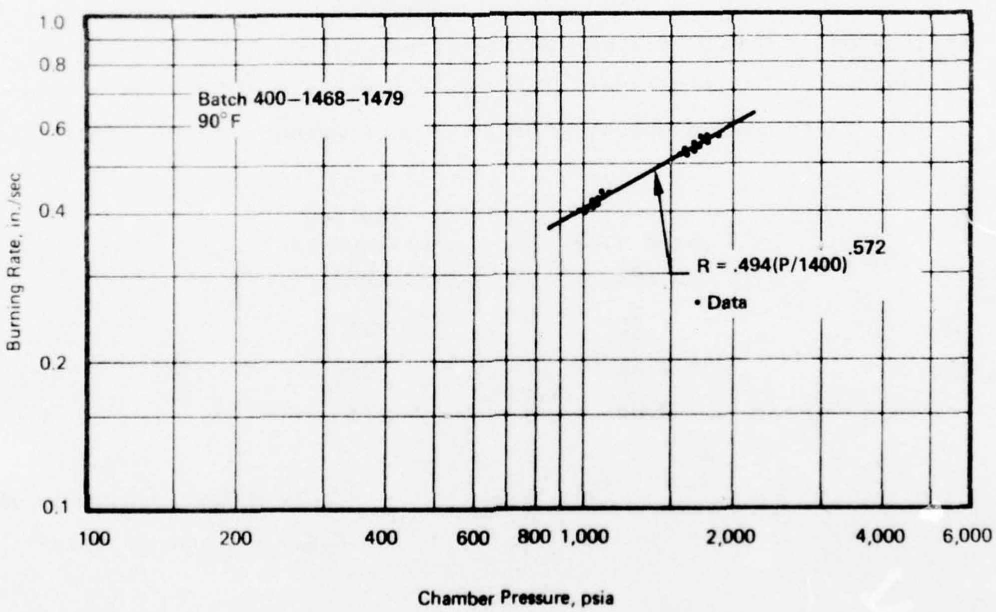


Figure 56. 4-lb Motor Test Data, Production Run No. 1

Table 33 presents a summary of the 4-lb motor burning rate data obtained from the series of production runs of UTP-18,803A completed under this effort. As shown, the one standard deviation for the last three series of production runs was consistently at 1.4%, which compares to a one standard deviation range of 1.3 to 2.3 for the previous production runs. The improvement in the 4-lb motor burning rate reproducibility was due to a redesign of the 4-lb motor hardware to increase the accuracy of mandrel placement during casting and improved data analysis techniques. Both the design and analysis changes are now standard operations for the 4-lb ballistic test motor.

A closer analysis of the last three production runs also reveals that, not only is the standard deviation for each production run the same, but the one standard deviation for the three production runs when considered as a single population is also 1.4% (table 34).

As a further point of interest in terms of propellant reproducibility, CSD conducted a series of tests on the production propellant to determine the effect on motor burning rate of using (1) expendable fiberglass cartridges in place of the standard reuseable steel cartridges and (2) a 6-day propellant cure rather than a 10-day cure. The expendable cartridge approach was desirable since it would reduce test costs and contribute to further improving the burning rate reproducibility because the steel cartridges tended to change dimensionally after several reuses and thus changed the grain web thickness, which induced uncertainties in the data reduction. The 6-day cure for the 4-lb motors was of interest since it would enable the testing of these motors to be completed before shipment of the 15-lb and 70-lb BATES motors to AFRPL.

A series of tests (volume II) was conducted to examine the viability of using the fiberglass cartridge. These tests consisted of casting the standard four 4-lb motors from each production batch but with two of the motors being cast with the steel cartridge and two being cast with the fiberglass cartridge. All four motors were then cured for the full ten days and tested. As illustrated in figure 57, the burning rates for the two types of cartridges

TABLE 33. UTP-18,803A 4-1b BURNING RATE SUMMARY

T2416

Production Run No.	Batches	Grind Ratio	NCO/OH	Burning Rate at 1400 psia	Pressure Exponent	One Standard Deviation, %
2	400-1468 to 1476	65/35	0.85	0.498	0.537	2.1
3	400-1480 to 1484	65/35	0.85	0.487	0.504	1.9
3	400-1485 to 1491	66/34	0.85	0.488	0.471	1.5
2A	400-1495 to 1503*	66/34	0.85	0.500	0.517	2.1
3A	400-1505 to 1515	66/34	0.82	0.495	0.529	2.0
4	400-1516 to 1525	68/32	0.82	0.472	0.473	1.3
5	400-1527 to 1537	67/33	0.81	0.493	0.475	1.5
6	400-1539 to 1543	67/33	0.81	0.475	0.450	2.3
7	400-1546 to 1557	68/32	0.82	0.480	0.469	1.7
8	400-1574 to 1582	67/33	0.81	0.474	0.525	1.3
9	400-1588 to 1600	67/33	0.81	0.480	0.556	1.4
10	400-1606 to 1615	See Table 21	0.81	0.477	0.522	1.4
11	400-1620 to 1629		0.81	0.474	0.510	1.4

*Aged fuel premix

TABLE 34. UTP-18,803A BURNING RATE REPRODUCIBILITY
PRODUCTION CASTINGS 9, 10, AND 11

$\overline{X}$ = 0.4076 in./sec
S_X = 0.0058 in./sec (1.42%)
n = 33 samples

Production Run No.	400-gal Batch	90°F, 4-lb Motor $r_{1,000}$, in./sec	Production Run No.	400-gal Batch	90°F, 4-lb Motor $r_{1,000}$, in./sec
9	1588	0.3985	10	1610	0.4175
9	1589	0.4084	10	1611	0.4097
9	1590	0.4072	10	1612	0.4066
9	1591	0.4116	10	1613	0.4084
9	1592	0.4084	10	1614	0.4117
9	1593	0.4030	10	1615	0.4076
9	1594	0.4073	11	1620	0.4116
9	1595	0.4122	11	1621	0.4014
9	1596	0.4111	11	1622	0.4074
9	1597	0.4161	11	1623	0.3966
9	1598	0.4163	11	1624	0.4002
9	1599	0.4170	11	1625	0.4025
9	1600	0.4172	11	1626	0.4011
10	1606	0.4086	11	1627	0.4016
10	1607	0.4046	11	1628	0.4086
10	1608	0.4005	11	1629	0.4120
10	1609	0.3995			

were indistinguishable. Therefore, the fiberglass cartridge was incorporated into the test and is now the standard 4-lb motor cartridge in use at CSD.

In determining the effect of the 6-day cure vs the 10-day cure, four 4-lb motors were cast from several production batches. Two of each group of four were taken out of cure after 6 days and tested and two of each group were tested after the standard 10-day cure. As shown in figures 58 and 59 and in volume II, the 4-lb motor burning rates after both the 6-day and 10-day cures were essentially the same.

In summary, UTP-18,803A exhibits very good ballistic reproducibility and, as discussed in section 5.1.3, accurately predicts the propellant burning rate in the 84-in. ELSH and CHAR cartridges.

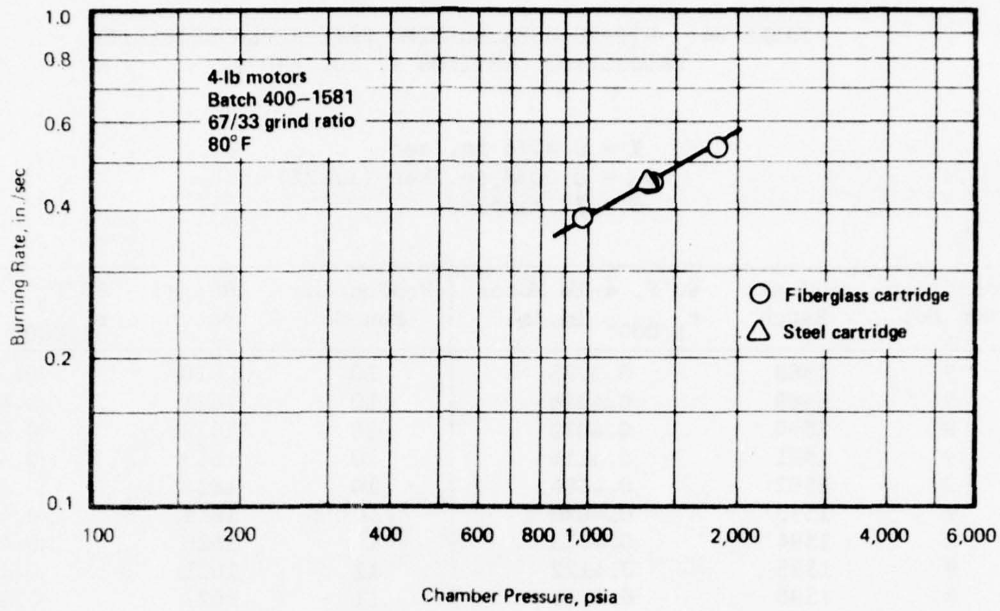


Figure 57. Effect of Cartridge Material on 4-lb Motor Propellant Burning Rate

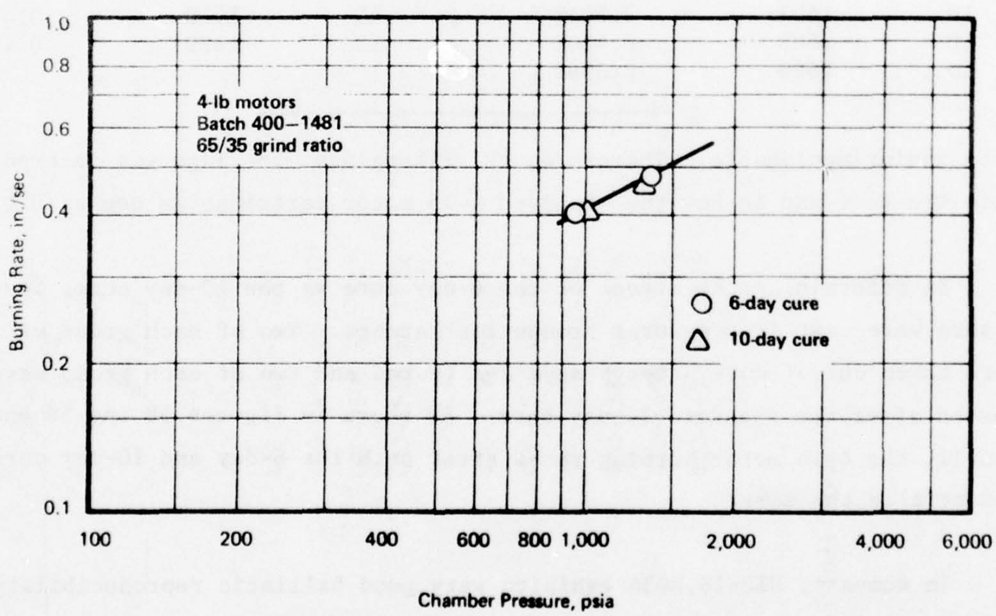


Figure 58. Effect of Cure Time on 4-lb Motor Propellant Burning Rate (Batch 400-1481)

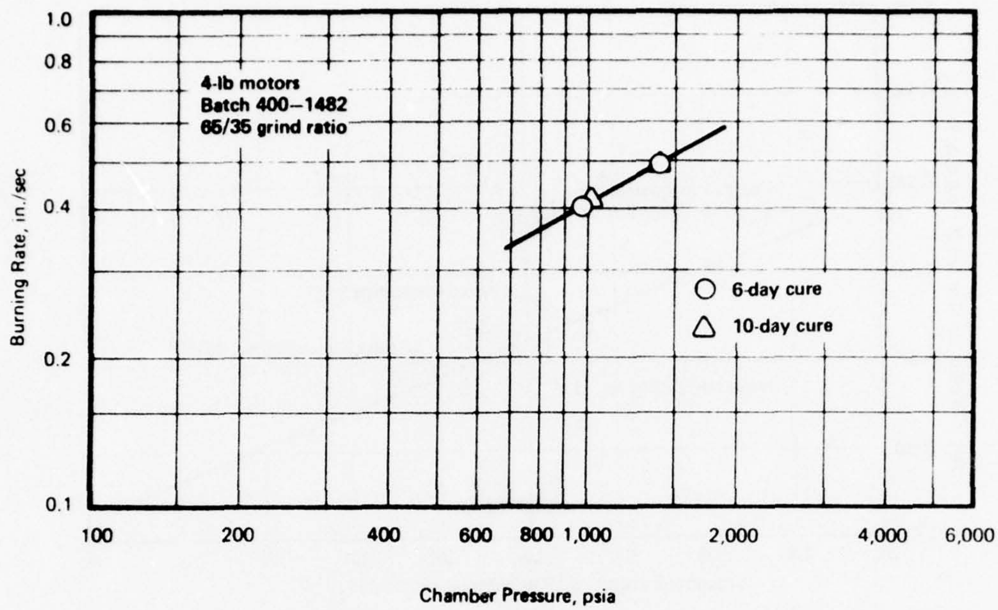


Figure 59. Effect of Cure Time on 4-lb Motor Propellant Burning Rate (Batch 400-1482)

5.1.2 Burning Rate Control

As discussed in section 3.1.4, the key to ensuring the adequate burning rate control for the uncatalyzed UTP-18,803A propellant is knowing the particle distribution for both the ground and unground AP and using this distribution to set the batch grind ratio. Figures 60 through 62 illustrate that, for the specific batches of UTP-18,803A for which the particle size distribution was used to set the grind ratio, the burning rate control was excellent.

Tables 35 through 38 summarize the various AP diameter calculations obtained for those propellant batches where particle size distribution data were obtained. The particle size distribution for each batch is given in section 3.0 of volume II. The method of calculating the AP particle diameters is described below.

Unground AP samples were collected from UTP-18,803A production batches with a stream sampler. These samples were classified using Tyler screens 35, 42, 60, 65, 80, 115, 150, and 200. The screen data were normalized using NBS beads. The ground AP samples were classified by MSA.

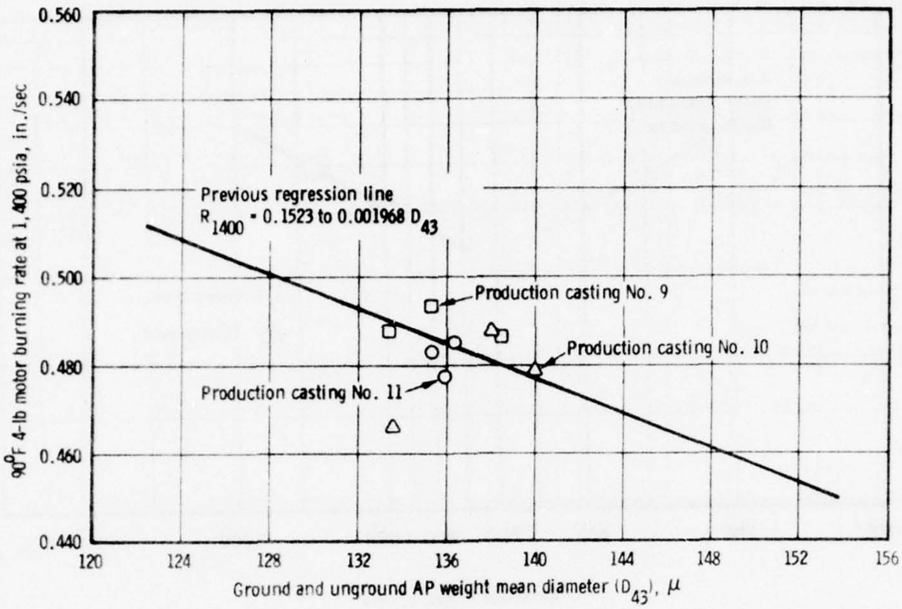


Figure 60. UTP-18,803A Production Experience, Grind Ratio Selected by AP Particle Diameter (D_{43})

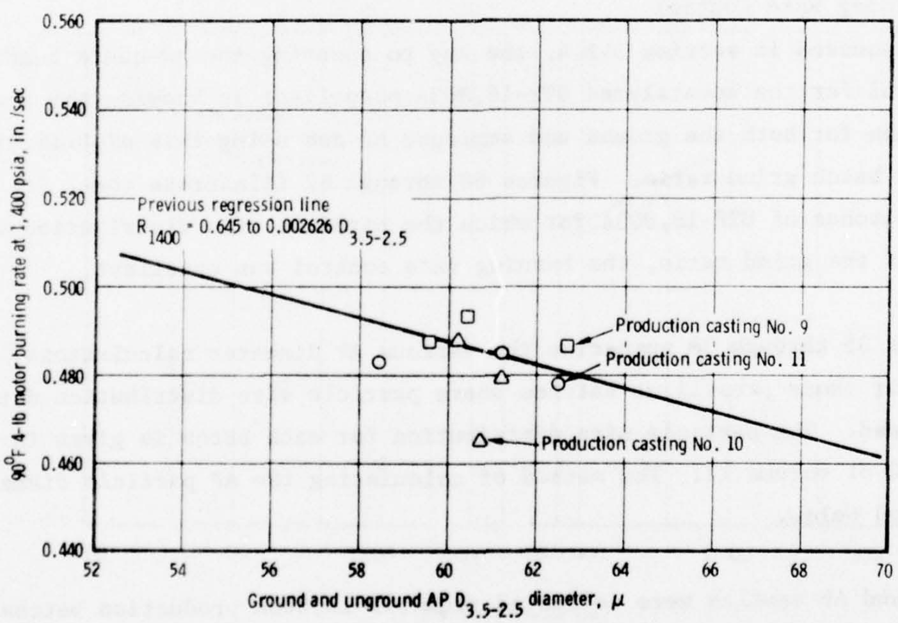


Figure 61. UTP-18,803A Production Experience, Grind Ratio Selected by AP Particle Diameter ($D_{3.5-2.5}$)

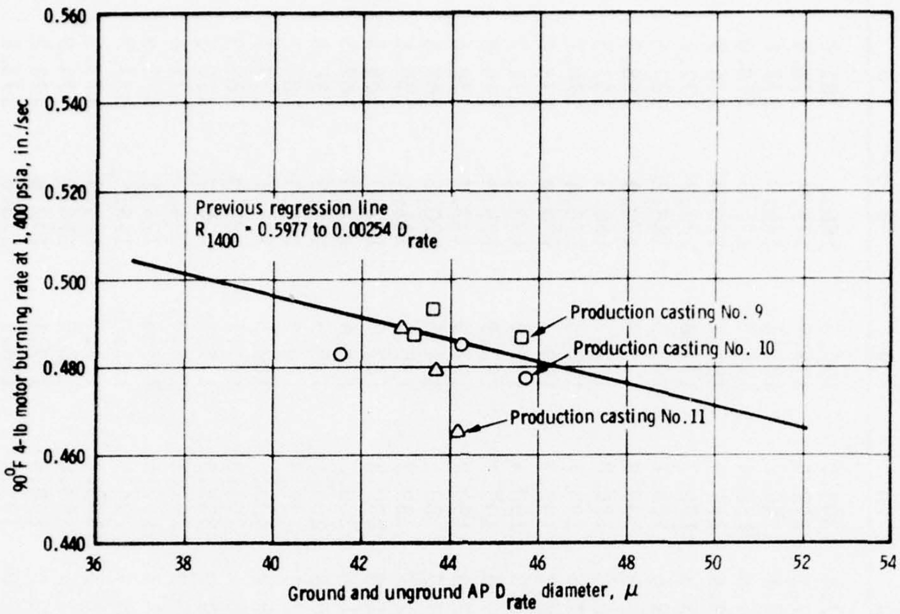


Figure 62. UTP-18,803A Production Experience, Grind Ratio Selected by AP Particle Diameter (D_{rate})

TABLE 35. UNGROUND AP PARTICLE DIAMETER DESCRIPTORS, PRODUCTION CASTINGS 1 THROUGH 7

Production Run No.	400-gal Batch	Grind Ratio	D_{10}, μ	D_{21}, μ	D_{30}, μ	D_{32}, μ	D_{43}, μ	$D_{3.5-2.5}$, μ	D_{rate}, μ	$D_{mass\ median}$ μ
2	1468	65/35	132.6	152.9	153.2	177.4	203.0	190.3	186.1	181.8
2	1472	65/35	125.8	143.9	144.6	167.1	192.9	179.9	175.7	170.9
2	1474	65/35	126.0	144.4	145.1	168.1	194.2	181.1	176.8	172.6
4	1516	68/32	126.0	143.7	144.4	164.8	188.4	176.5	172.6	170.0
4	1518	68/32	128.4	146.5	147.2	169.5	194.9	182.1	178.0	176.7
4	1522	68/32	125.4	142.7	143.5	165.3	190.7	177.8	173.7	172.1
4	1526	66/34	134.4	154.7	155.1	179.4	205.1	192.3	188.2	187.5
5	1527	67/33	117.0	137.2	137.5	161.9	188.8	175.3	170.9	168.9
5	1530	67/33	119.3	137.4	137.9	160.0	186.0	172.7	168.5	151.5
5	1531	67/33	123.7	143.6	143.9	167.6	193.7	180.6	176.4	174.2
5	1532	67/33	114.3	143.2	140.3	168.7	192.3	180.7	176.9	173.0
5	1533	67/33	123.3	141.9	142.4	165.0	190.4	177.6	173.5	171.7
5	1534	67/33	104.8	141.2	136.0	169.9	195.3	182.9	178.8	176.8
5	1535	67/33	122.1	141.9	142.0	163.3	190.8	177.9	173.7	158.6
5	1536	67/33	70.6	121.4	111.0	159.6	188.1	174.5	170.1	167.5
5	1537	67/33	118.7	137.7	138.4	162.1	189.2	175.5	171.1	170.6
6	1539	67/33	48.4	122.1	100.4	171.6	200.8	187.3	182.9	184.5
6	1540	67/33	65.4	128.6	112.9	171.1	200.0	186.4	182.0	182.5
6	1541	67/33	110.0	146.2	141.7	176.8	203.4	190.5	186.3	186.3
6	1542	67/33	119.6	145.1	144.1	172.5	199.5	186.2	181.8	180.7
6	1543	67/33	115.9	141.3	140.3	168.7	195.8	182.5	178.1	177.7
7	1546	68/32	72.6	137.8	121.4	178.7	205.8	193.1	189.0	189.9
7	1547	68/32	97.9	130.8	127.3	160.9	188.8	175.1	170.7	170.3
7	1548	68/32	115.8	140.4	139.2	165.9	191.5	178.8	174.7	171.6
7	1549	68/32	113.4	137.7	137.0	164.7	192.5	178.6	174.1	173.6
7	1551	68/32	79.8	128.5	119.4	165.9	194.9	181.0	176.5	177.2
7	1552	68/32	81.2	126.6	119.0	162.5	192.3	177.9	173.3	173.9
7	1553	68/32	91.2	135.3	127.4	167.4	193.0	180.7	176.7	174.9
7	1554	68/32	106.1	134.4	132.5	163.0	190.9	177.1	172.6	172.2
7	1555	68/32	67.5	121.8	110.1	162.6	191.9	178.1	173.6	173.6
7	1556	68/32	91.9	137.1	129.0	170.1	197.1	184.1	179.8	178.7
7	1557	68/32	127.9	147.3	147.7	171.2	197.0	184.1	179.9	177.8

TABLE 36. GROUND AND UNGROUND AP PARTICLE DIAMETER DESCRIPTORS, PRODUCTION CASTINGS 1 THROUGH 7

Production Run No.	400-gal Batch	Grind Ratio	D_{10}, μ	D_{21}, μ	D_{30}, μ	D_{32}, μ	D_{43}, μ	$D_{3.5-2.5}$, μ	D_{rate}, μ	$D_{mass\ median}$ μ
2	1468	65/35	2.874	3.990	5.718	16.297	135.7	56.59	39.46	146.7
2	1472	65/35	3.024	4.199	5.942	16.524	129.0	54.89	38.65	133.1
5	1527	67/33	3.696	5.212	7.353	20.635	130.6	61.48	45.47	133.1
5	1535	67/33	3.284	4.582	6.570	18.843	131.7	59.88	43.59	137.2
7	1546	68/32	3.441	4.857	6.975	20.308	143.7	65.45	47.61	154.3
7	1554	68/32	3.0276	4.186	6.066	17.615	133.2	58.92	42.34	135.6

TABLE 37. GROUND AP PARTICLE DIAMETER DESCRIPTORS, PRODUCTION CASTINGS 1 THROUGH 7

Production Run No.	400-gal Batch	Grind Ratio	D_{10}, μ	D_{21}, μ	D_{30}, μ	D_{32}, μ	D_{43}, μ	$D_{3.5-2.5}$, μ	D_{rate}, μ	$D_{mass\ median}$ μ
1	1458	66/34	2.863	3.718	3.989	5.964	10.680	8.012	7.244	8.00
1	1464	66/34	2.994	3.932	4.220	6.382	11.197	8.530	7.751	9.00
2	1468	65/35	2.8698	3.758	4.029	6.066	10.789	8.134	7.367	8.30
2	1472	65/35	3.019	3.936	4.188	6.181	10.388	8.071	7.387	8.30
2	1476	65/35	3.166	4.069	4.328	6.295	10.823	8.267	7.526	8.00
3	1480	65/35	3.174	4.050	4.302	6.193	10.501	8.077	7.372	8.20
3	1484	65/35	2.880	3.783	4.031	6.012	10.229	7.898	7.215	8.20
3	1488	66/34	2.846	3.806	4.098	6.351	11.242	8.554	7.767	9.10
2A	1495	66/34	3.408	4.398	4.676	6.824	11.369	8.865	8.126	9.20
2A	1499	66/34	3.068	4.254	4.603	7.472	13.204	10.140	9.231	11.00
2A	1503	66/34	3.683	4.763	5.056	7.366	12.232	9.548	8.755	9.80
3A	1505	66/34	3.714	4.752	4.984	7.017	10.834	8.767	8.146	9.0
3A	1509	66/34	2.729	3.691	3.942	6.082	10.247	8.008	7.341	8.60
3A	1513	66/34	3.582	4.643	4.880	6.989	10.904	8.796	8.161	9.20
4	1516	68/32	3.963	5.102	5.399	7.781	12.737	10.002	9.193	10.20
4	1520	68/32	3.956	4.852	5.113	6.963	11.768	8.797	8.100	8.20
4	1524	68/32	2.981	3.881	4.157	6.208	10.578	8.189	7.481	8.80
5	1527	67/33	3.684	4.783	5.081	7.445	12.391	9.672	8.868	9.80
5	1535	67/33	3.276	4.242	4.540	6.730	11.852	8.973	8.138	9.10
7	1546	68/32	3.432	4.494	4.771	7.041	11.784	9.169	8.398	9.60
7	1550	68/32	3.459	4.473	4.699	6.705	10.558	8.456	7.829	8.40
7	1554	68/32	3.021	3.887	4.149	6.084	10.689	8.076	7.323	7.80

TABLE 38. AP PARTICLE DIAMETER DESCRIPTORS, PRODUCTION CASTINGS 8 THROUGH 11

			Ground and Unground			Unground		
Production Run No.	400-gal Batch	Grind Ratio	D_{43}, μ	$D_{3.5-2.5}$, μ	D_{rate}, μ	D_{43}, μ	$D_{3.5-2.5}$, μ	D_{rate}, μ
8	1574	67/33	131.1	64.3	48.5	189.1	174.8	170.3
8	1575	67/33	137.7	65.7	49.0	198.8	183.7	178.9
8	1576	67/33	141.1	68.02	51.0	203.6	188.1	183.2
8	1577	67/33	130.4	65.0	49.5	187.7	173.3	168.7
8	1578	67/33	132.8	66.1	50.2	191.1	177.0	172.5
8	1579	67/33	133.2	63.6	47.4	192.6	177.7	173.0
8	1580	67/33	129.9	61.8	45.9	188.1	173.0	168.1
8	1581	67/33	133.1	64.7	48.6	192.1	177.7	173.0
8	1582	67/33	131.8	65.6	49.6	189.7	174.7	170.0
9	1588	67/33	138.4	62.7	45.6	200.5	186.5	181.8
9	1589	67/33	132.4	59.6	43.1	192.3	177.6	172.9
9	1590	67/33	135.3	60.5	43.6	196.6	181.0	176.0
9	1591	67/33	137.7	63.5	46.5	199.4	184.3	179.4
9	1592	67/33	141.1	64.7	47.2	204.6	189.2	184.3
9	1593	67/33	135.0	64.5	48.0	195.0	180.2	175.5
9	1594	67/33	137.1	65.3	48.6	197.9	183.7	179.1
9	1595	67/33	141.4	63.1	45.5	205.0	190.3	185.5
9	1596	67/33	133.0	60.7	44.2	193.4	179.7	175.3
9	1597	67/33	142.2	64.3	46.7	206.2	192.1	187.5
9	1598	67/33	132.0	62.5	46.4	190.8	177.3	172.9
9	1599	67/33	135.9	60.7	43.7	197.5	183.8	179.4
9	1600	67/33	136.6	61.9	45.0	198.0	183.3	178.6
10	1606	65/35	138.0	60.2	42.9	206.1	193.5	189.4
10	1607	68/32	133.6	60.7	44.1	191.5	178.0	173.7
10	1608	66/34	140.0	61.2	43.7	206.3	192.3	188.5
10	1609	66/34	134.5	59.6	42.8	197.7	184.8	180.6
10	1610	66/34	136.4	60.0	42.9	200.9	187.6	183.3
10	1611	66/34	135.0	59.1	42.3	198.7	185.2	180.8
10	1612	66/34	137.1	60.8	43.6	202.0	188.3	183.9
10	1613	66/34	136.9	62.5	45.5	201.1	186.8	182.2
10	1614	66/34	142.1	62.4	44.6	209.3	195.9	191.6
10	1615	66/34	134.9	58.3	41.4	198.6	184.6	180.0
11	1620	63/35	136.3	61.2	44.2	203.2	190.1	185.9
11	1621	66/34	135.3	58.4	41.5	199.2	187.2	183.3
11	1622	66/34	135.9	62.5	45.7	199.5	186.7	182.5
11	1623	66/34	133.5	62.6	46.1	195.8	182.8	178.7
11	1624	66/34	128.5	58.8	42.9	188.6	175.0	170.6
11	1625	66/34	129.6	62.5	46.7	189.4	176.3	172.1
11	1626	66/34	140.6	63.6	46.2	206.4	192.6	188.1
11	1627	66/34	137.6	62.7	45.6	201.9	187.8	183.3
11	1628	66/34	138.6	62.5	45.3	203.5	189.9	185.5
11	1629	66/34	135.7	61.3	44.5	198.9	185.4	181.0

The particle diameter descriptions were calculated by CSD's MA39 terminal computer program. The diameters calculated by the program were the following:

(1) Arthimetic mean, d_{10}

$$d_{10} = \frac{\Sigma D_{avg_i} N_i}{\Sigma N_i}$$

where

D_i = diameter corresponding to cumulative mass CMASS:

D_{avg_i} = average mass for particles in the ith size range

$$D_{avg_i} = \left[\frac{(D_{i+1}^2 + D_i^2)(D_{i+1} + D_i)}{4}\right]^{\frac{1}{3}}$$

$$N_i = \frac{CMASS_{i+1} - CMASS:}{(\text{density})(D_{avg_i}^3)}$$

(2) Mean surface diameter, d_{20}

$$d_{20} = \left[\frac{\Sigma D_{avg_i}^2 N_i}{\Sigma N_i}\right]^{\frac{1}{2}}$$

(3) Linear mean diameter, d_{21}

$$d_{21} = \frac{\Sigma D_{avg_i}^2 Ni}{\Sigma D_{avg_i} Ni}$$

(4) Mean weight diameters, d_{30}

$$d_{30} = \left[\frac{\Sigma D_{avg_i}^3 N_i}{\Sigma N_i}\right]^{\frac{1}{3}}$$

(5) Surface mean diameter, d_{32}

$$d_{32} = \frac{\Sigma D_{avg_i}^{3} N_i}{\Sigma D_{avg_i}^{2} N_i}$$

(6) $d_{3.5\ 2.5}$

$$d_{3.5\ 2.5} = \frac{\Sigma D_{avg_i}^{3.5} N_i}{\Sigma D_{avg_i}^{2.5} N_i}$$

(7) Weight mean diameter, d_{43}

$$d_{43} = \frac{\Sigma D_{avg_i}^{4} N_i}{\Sigma D_{avg_i}^{3} N_i}$$

(8) d_{rate}

$$d_{rate} = \frac{\Sigma D_{avg_i}^{(8/3)} N_i}{\Sigma D_{avg_i}^{3} N_i}$$

5.1.3 Burning Rate Scaleup Effects

Experience with PBAN and CTPB propellants has shown that most propellants exhibited burning rate sacleup effects as the motor size increased. To determine to what extent, if any, UTP-18,803A exhibited motor size burning rate effects, test data from 4-lb motors were compared with test data from AFRPL's 15-lb BATES, 70-lb BATES, and 84-in. CHAR motors. As shown in figure 63 and in volume II, the burning rates obtained from the 4-lb motors, the 15- and 70-lb BATES, and the 84-in. CHAR motor were the same. UTP-18,803A does not exhibit any burning rate scaleup effect due to motor size.

5.1.4 4-lb Motor Correlation with LSBR and CSBR

The propellant processing specification for UTP-18,803A requires that the acceptance of the propellant be based on LSBR data (3/8-in. straw), which is

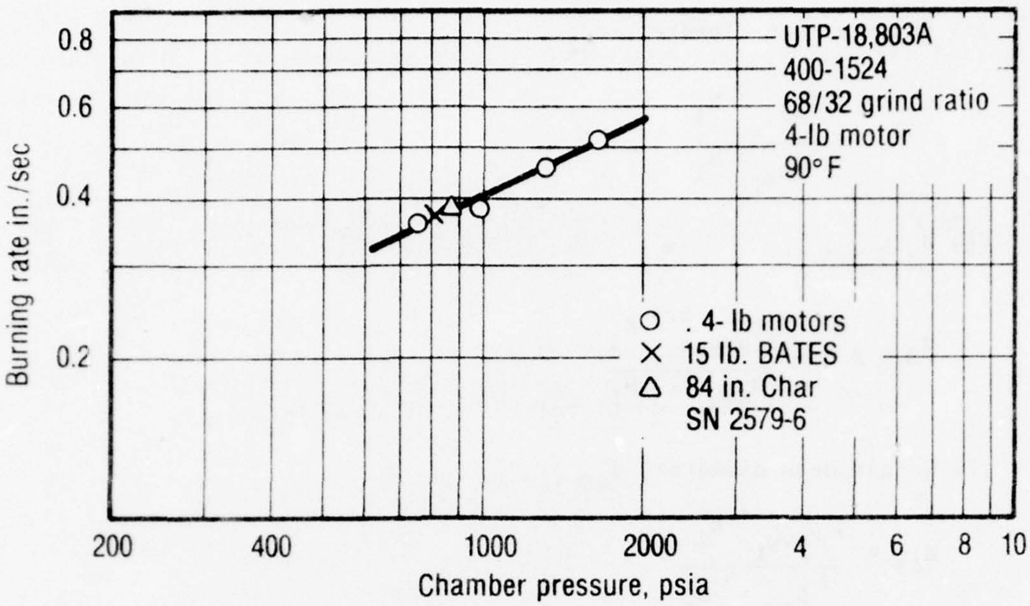


Figure 63. Motor Scaleup, UTP-18,803A

the standard practice at CSD. It was of interest to know how well the LSBR data correlated with the 4-lb motor data. In addition, CSBR data were taken to determine if any correlation between CSBR and 4-lb motor data could be obtained to allow substitution of CSBRs for the 4-lb motor.

The 4-lb motor burning rate data were corrected to 90°F and to chamber pressures of 1,000 and 1,400 psia. These data were correlated by a least-squares regression with LSBR and CSBR burning rate data. These regressions are shown in figures 64 through 67. Examination of the correlation coefficients (R) of the regressions indicates the LSBR regressions were statistically better than the CSBR regressions. A correlation coefficient of 1.0 is a perfect fit of the data (i.e., all data points fall on the calculated regression line). Based on past experience, motor burning rate-LSBR/CSBR regressions tend to have low correlation coefficients because a majority of the data fall about the nominal burning rate. Therefore, the 0.648 correlation coefficient (figure 65) is a good fit of the 4-lb motor and LSBR burning rates at 1,000 psia.

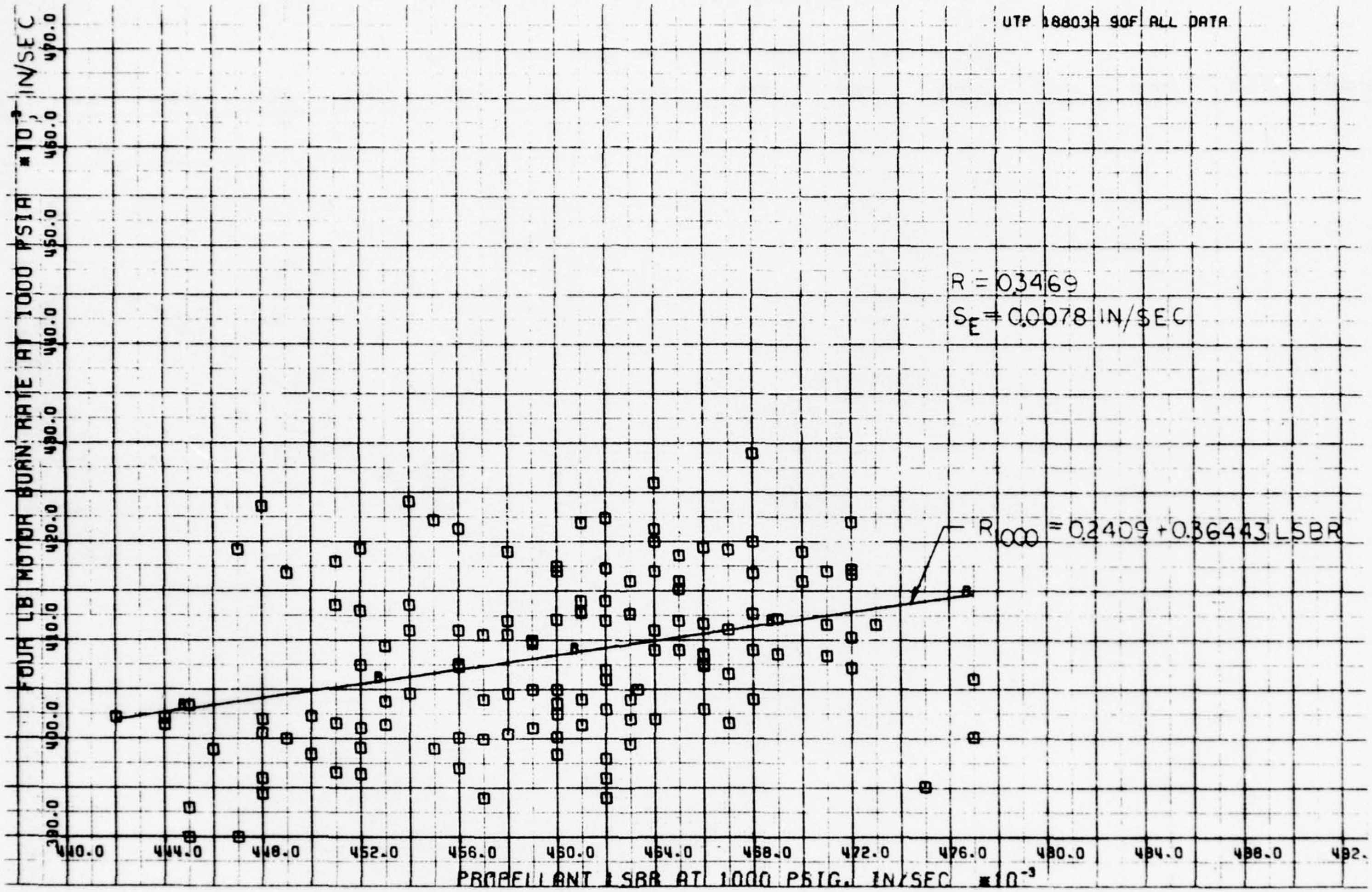
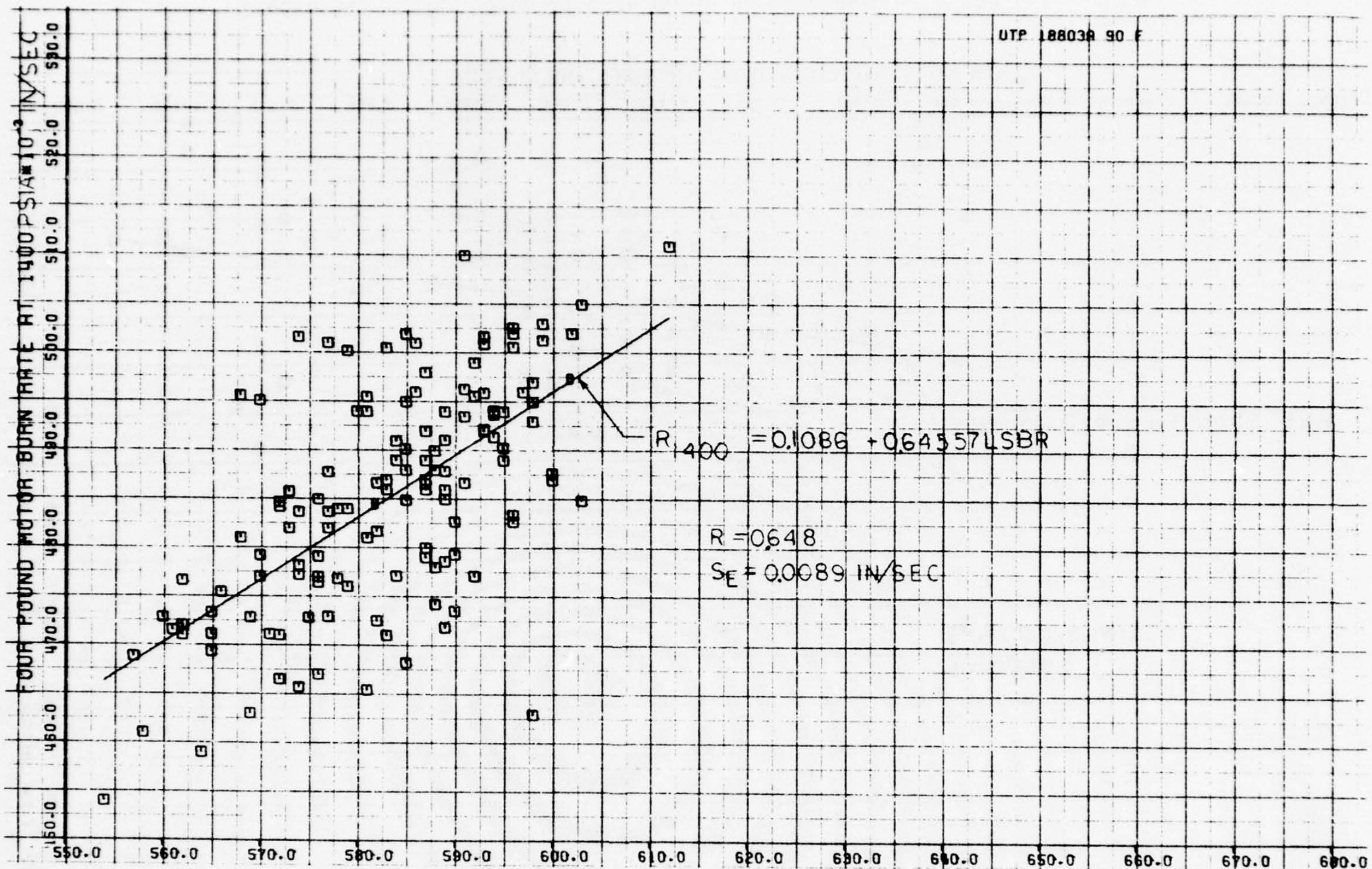


Figure 64. Correlation of 4-lb Motor Burning Rate at 1,000 psi vs LSBR



Propellant LSBR at 1,400 psig, in./sec x 10^3

Figure 65. Correlation of 4-lb Motor Burning Rate at 1,400 psi vs LSBR

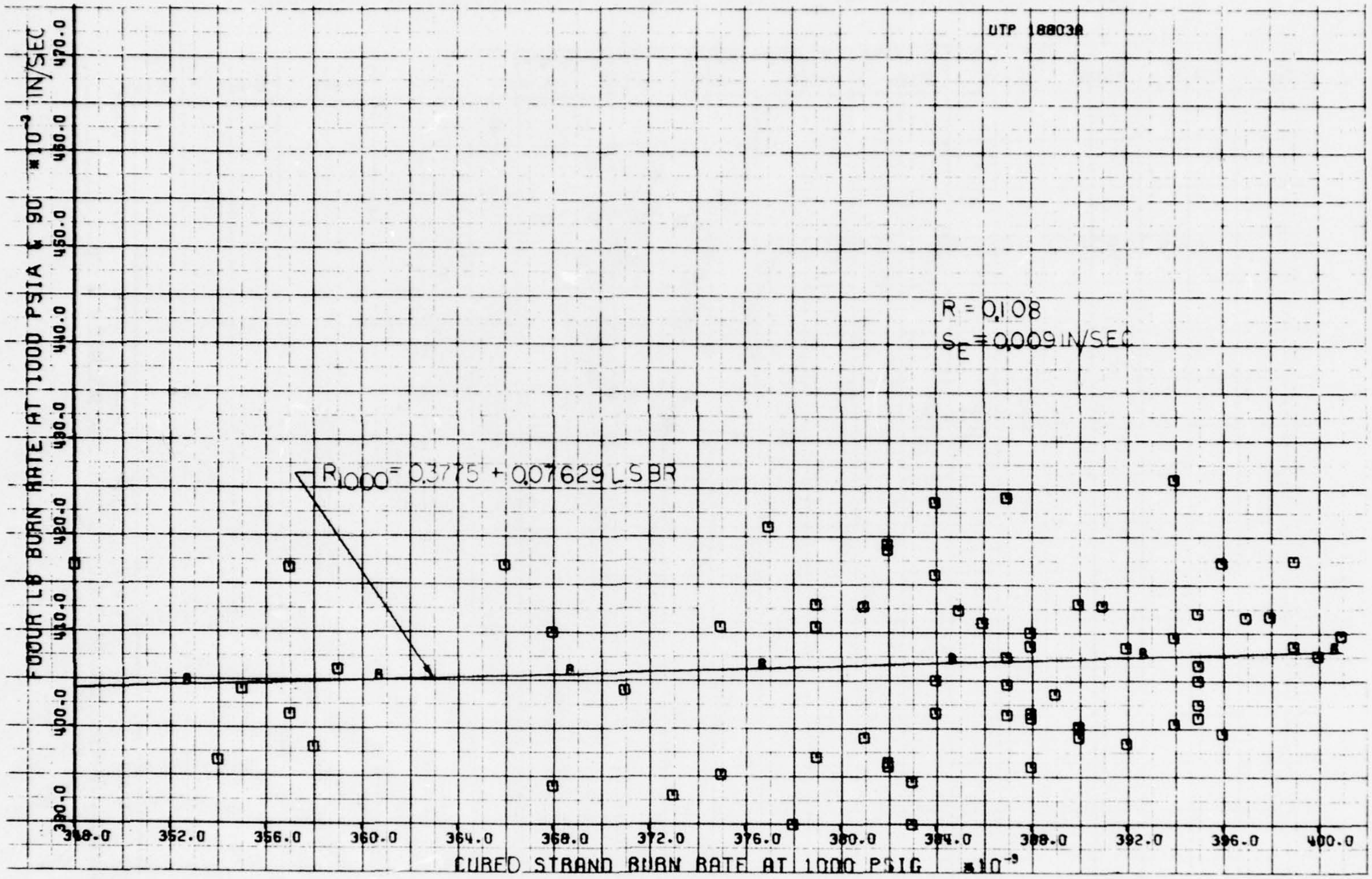


Figure 66. Correlation of 4-1b Motor Burning Rate at 1,000 psi vs CSBR

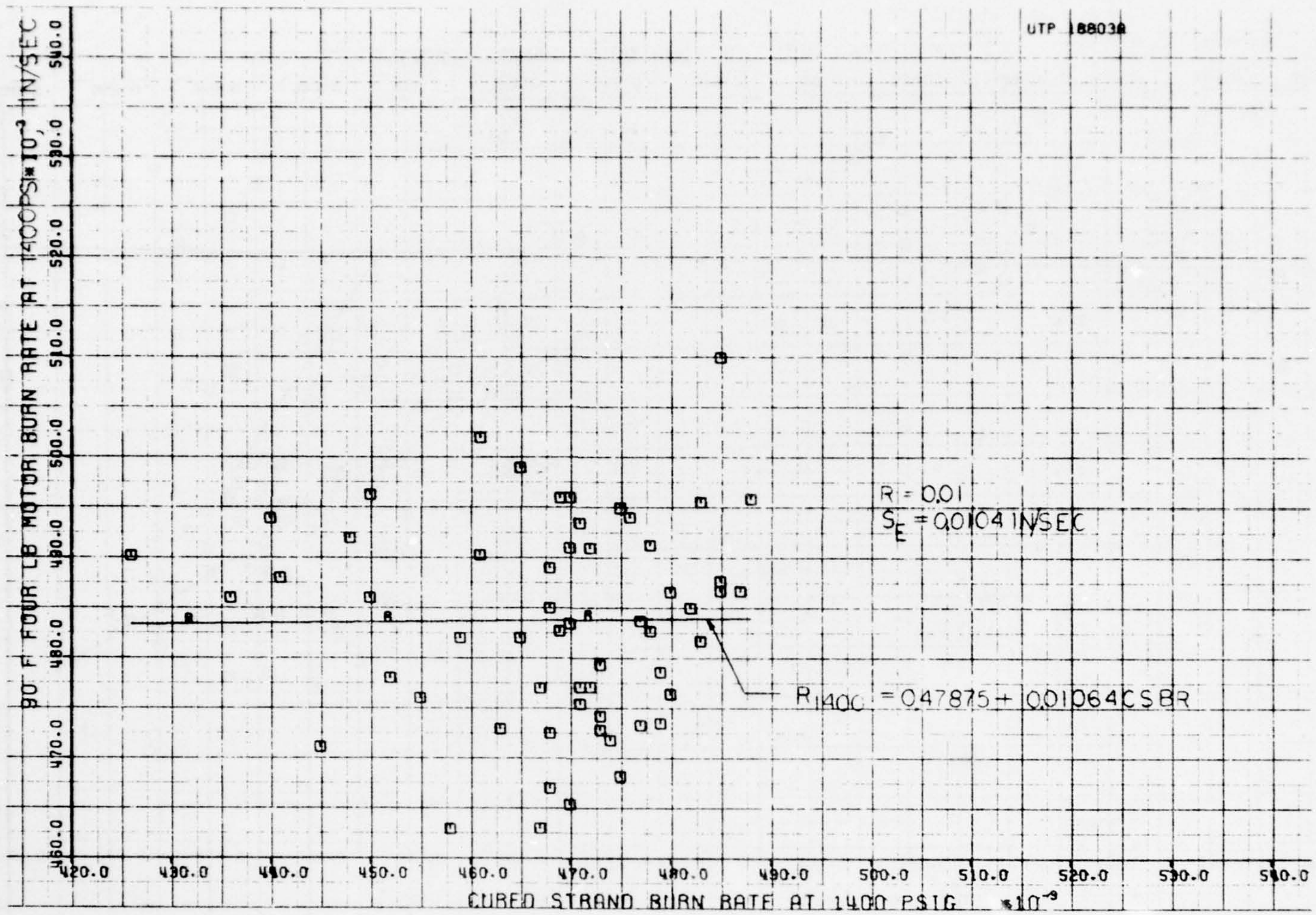


Figure 67. Correlation of 4-lb Motor Burning Rate at 1,400 psi vs CSBR

The standard error of estimate, SE, represents the one sigma deviation of the regression line. The SE of these regressions varied from 0.0078 to 0.010 in./sec.

Based on these analyses, it is not felt, as expected, that either the LSBR or CSBR data can be used in place of the 4-lb motor, particularly in view of the excellent ballistic results obtained from the 4-lb motor.

5.2 MECHANICAL PROPERTIES

During the course of this program, UTP-18,803A physical properties were monitored to determine the variance which was encountered under production conditions. The properties monitored were the QC processing and physical properties, BIT samples, propellant density, and liner/propellant peel data. Each is discussed below.

5.2.1 QC Processing and Physical Properties

As part of the standard processing procedure for UTP-18,803A, the following propellant properties were monitored for each propellant batch: (1) percent IPDI at one hour after addition; (2) propellant viscosity measured 1 hr after IPDI addition; (3) maximum corrected stress; (4) maximum corrected strain; and (5) initial tangent modulus. A statistical evaluation of each of these properties for each of the production runs is given in table 39.

5.2.2 Bond-in-Tension Data

Bond-in-tension samples were cast for each of the 84-in. cartridges cast under this program. Table 40 summarizes the data obtained.

5.2.3 Density

Propellant density was determined for a number of batches of UTP-18,803A. The data are summarized in table 41.

5.2.4 Peel Data

One set of peels was tested for each of the 84-in. cartridges loaded with UTP-18,803A. Table 42 summarizes the data obtained.

TABLE 39. UTP-18,803A QC PROCESSING AND PHYSICAL PROPERTIES

Production Run No.	Batch	Grind Ratio	NCO/OH Ratio	Wt % IPDI*		Viscosity* Kp @ 5000 dynes/cm^2		Max Corrected Stress, σ^c_m, psi		Max Corrected Strain, ϵ^c_m, %		Initial Tangent Modulus, E_o, psi	
				X	Sx	X	Sx	X	Sx	X	Sx	X	Sx
2	400-1468 to 1479	65/35	0.85	0.374	0.005	6.57	1.12	125	8.9	29.8	3.6	821	158
3	1480 to 1484	65/35	0.85	0.372	0.001	4.98	0.7	149	9.6	33.0	2.9	957	105
3	1485 to 1491	66/34	0.85	0.371	0.007	6.1	1.67	147	5.1	35.9	2.3	984	132
2A	1495 to 1503**	66/34	0.85	0.403	0.011	6.6	1.1	174	5.2	27.0	2.4	1540	125
3A	1505 to 1515	66/34	0.82	0.389	0.001	5.84	1.5	124	9.3	32.9	2.9	778	144
4	1516 to 1526	68/32	0.82	0.359	0.003	4.56	0.6	114	2.5	36.7	3.5	575	69.5
5	1527 to 1537	67/33	0.81	0.377	0.001	5.27	0.9	103	2.2	35.8	2.1	619	88
6	1539 to 1543	67/33	0.81	0.386	0.009	5.73	1.4	103	10	37.2	6.3	453	74
7	1546 to 1557	68/32	0.82	0.384	0.010	5.46	0.8	119	13.7	30.1	6.7	806	156
8	1574 to 1582	67/33	0.81	0.369	0.002	5.29	0.5	117	4.4	37.6	3.0	560	73.8
9	1588 to 1600	67/33	0.81	0.388	0.010	3.85	1.03	101	7.6	32.5	3.1	770	153
10	1606 to 1615	See table 21	0.81	0.367	0.001	5.84	0.66	109	6.7	37.5	2.7	864	101
11	1620 to 1629		0.81	0.356	0.012	6.19	0.5	122	8.9	35.0	2.2	956	117

*Measured at one hour after IPDI addition

** Aged fuel premix

TABLE 40. UTP-18,803A, UTL-0040A BOND-IN-TENSION

Production Run No.	400-gal Batch	Tensile Value of Silica - Asbestos NBR Sample	Tensile Value of Fiberglass Sample	Failure Mode
1	1454	112	137	Propellant
1	1455	107	106	Propellant
1	1456	115	112	Propellant
1	1459	106	119	Propellant
1	1460	120	150	Propellant
1	1463	126	113	Propellant
1	1464	127	97	Propellant
1	1465	132	107	Propellant
2	1469	100	100	Propellant
2	1473	125	125	Propellant
2	1477	113	104	Propellant
2	1479	108	112	Propellant
3	1481	129	109	Propellant
3	1485	136	112	Propellant
3	1489	123	108	Propellant
3	1491	130	118	Propellant
2A	1496	128	121	Propellant
2A	1500	120	132	Propellant
3A	1505	118	107	Propellant
3A	1510	121	114	Propellant
3A	1514	93	81	Propellant
3A	1515	83	88	Propellant
4	1517	93	101	Propellant
4	1521	96	113	Propellant
4	1525	79	96	Propellant
4	1526	100	110	Propellant
5	1528	88	78	Propellant
5	1533	70	80	Propellant
6	1639	90	95	Propellant
6	1543	109	121	Propellant
7	1546	84	110	Propellant
7	1551	100	101	Propellant
7	1556	99	85	Propellant
8	1574	109	95	Propellant
8	1578	113	79	Propellant
9	1588	94	91	Propellant
9	1592	111	92	Propellant
10	1606	108	76	Propellant
11	1625	*	83	Propellant

* No sample made

TABLE 41. UTP-18,803A DENSITY

$\bar{X}$ = 1.84515 gm/cc = 0.0667 lb/in.^{3}
S_X = 0.00236 gm/cc = 0.13%
n = 22

Production Run No.	400-gal Batch	Density, gm/cc	Production Run No.	400-gal Batch	Density, gm/cc
N/A	1450	1.8454	1	1464	1.8448
1	1454	1.8447	1	1465	1.8466
1	1455	1.8444	8	1574	1.8424
1	1456	1.8440	8	1578	1.8437
1	1457	1.8439	9	1589	1.8412
1	1458	1.8534	9	1598	1.8456
1	1459	1.8470	9	1600	1.8464
1	1460	1.8468	10	1608	1.8424
1	1461	1.8458	10	1615	1.8460
1	1462	1.8452	11	1620	1.8442
1	1463	1.8450	11	1623	1.8444

TABLE 42. UTP-18,803A, UTL-0040A LINER 180° PEEL

Production Run No.	Batch	Value, lb/in.^{2}	Failure Mode
2A	1496	33.4	Partial peel, liner voids
2A	1498	36.1	Partial peel, cohesive liner break in propellant
4	1517	23.1	Propellant
4	1521	18.5	Propellant
4	1525	23.8	Propellant
4	1526	19.2	Propellant
5	1528	19.0	Propellant
5	1533	18.0	Propellant
5	1537	16.0	Propellant
6	1539	16.4	Propellant
6	1543	18.0	Propellant
7	1546	20.0	Propellant
7	1556	19.0	Propellant
8	1574	20.4	Propellant
8	1578	20.5	Propellant
9	1588	22.2	Propellant
9	1593	21.1	Propellant
9	1594	24.1	Propellant
9	1597	26.0	Propellant
10	1606	21.0	Propellant
10	1610	19.0	Propellant

5.2.5 Comparison of Preproduction and Production Propellant Properties

As discussed previously, a series of nine 5-gal mixes and one 400-gal mix was made to characterize UTP-18,803A with the specific chemical lots to be used in propellant production before initiating the propellant processing for the 84-in. cartridges. The nine 5-gal mixes examined the effects of curative ratio on mechanical properties (0.80, 0.83, and 0.86). Based on the results of these mixes, the 400-gal preproduciton batch was made with a curative ratio of 0.85. During the processing of the 137 400-gal production batches, curative ratios of 0.81, 0.82, and 0.85 were used to adjust the mechanical properties as required as production experience was gained with UTP-18,803A (tables 43 through 45).

The data obtained from the preproduction and production mixes are illustrated in figures 68 and 69. As shown, there was a significant effect of curative ratio on the maximum corrected stress as expected; however, the effect was more pronounced at the 5-gal scale than for the 400-gal size. Also note in figure 68 that although the 400-gal preproduction batch was considerably lower than the mean for the 400-gal production batches, it was still within the one standard deviation calculated for the production batches at a curative ratio of 0.85. The data for the maximum corrected strain (figure 69) were more consistent with the 5-gal mixes generally falling within the one standard deviation calculated for the 400-gal production batches.

TABLE 43. UTP-18,803A, ICRPG CLASS B PHYSICAL PROPERTIES, 0.81 NCO/OH RATIO

	σ_m^c, psi	ε_m^c, %	E_o, psi
$\overline{X}$	109.63	35.40	758.5
S_X	10.32	3.25	180.5
n = 52			

Production Run No.	400-gal Batch	Maximum Corrected Stress, psi	Maximum Corrected Strain, %	Initial Tangent Modulus, psi
5	1527	103	37	717
5	1528	102	34	728
5	1529	104	35	592
5	1530	103	38	614
5	1532	105	39	553
5	1533	104	36	621
5	1534	106	34	617
5	1535	101	38	478
5	1536	100	33	529
5	1537	99	34	741
8	1574	117	34	634
8	1575	120	39	603
8	1576	116	42	463
8	1577	113	34	579
8	1578	113	36	431
8	1579	119	35	635
8	1580	125	41	537
8	1581	120	39	542
8	1582	111	38	618
9	1588	97	31	813
9	1589	102	30	952
9	1590	101	34	588
9	1591	99	36	600
9	1592	97	31	694
9	1593	92	34	588
9	1594	101	36	867
9	1595	97	37	661
9	1596	98	32	632
9	1597	90	29	761
9	1598	113	34	952
9	1599	116	32	896
9	1600	109	26	1,005
10	1606	114	42	746
10	1607	118	38	966
10	1608	112	37	884
10	1609	100	36	706
10	1610	107	40	805
10	1611	99	33	838
10	1612	102	38	828
10	1613	112	38	866
10	1614	114	34	1,015
10	1615	113	39	985
11	1620	127	38	1,062
11	1621	127	34	1,100
11	1622	126	34	1,104
11	1623	110	32	806
11	1624	113	36	810
11	1625	106	31	952
11	1626	124	36	1,010
11	1627	123	36	916
11	1628	128	37	816
11	1629	133	34	988

TABLE 44. UTP-18,803A, ICRPG CLASS B PHYSICAL PROPERTIES, 0.82 NCH/OH RATIO

	σ_m^c, psi	ϵ_m^c, %	E_o, psi
$\bar{X}$	118.8	33.15	721.9
S_X	10.3	5.38	163.5
n = 34			

Production Run No.	400-gal Batch	Maximum Corrected Stress, psi	Maximum Corrected Strain, %	Initial Tangent Modulus, psi
3A	1505	98	36	534
3A	1506	129	31	930
3A	1507	126	31	744
3A	1508	121	27	1,057
3A	1509	127	35	894
3A	1510	124	35	822
3A	1511	120	32	669
3A	1512	132	34	717
3A	1513	126	35	670
3A	1514	128	36	732
3A	1515	131	30	786
4	1516	112	34	561
4	1517	116	31	649
4	1518	120	40	651
4	1519	114	36	488
4	1520	115	42	468
4	1521	110	34	536
4	1522	113	38	508
4	1523	114	33	653
4	1524	113	36	594
4	1525	115	40	636
4	1526	114	40	568
7	1546	134	37	592
7	1547	134	32	706
7	1548	136	35	645
7	1549	131	33	821
7	1550	124	35	726
7	1551	107	24	1,056
7	1552	104	24	812
7	1553	102	22	891
7	1554	105	18	1,081
7	1555	122	28	875
7	1556	121	34	834
7	1557	102	39	638

TABLE 45. UTP-18,803A ICRPG CLASS B PHYSICAL PROPERTIES
0.85 NCO/OH RATIO

(Sheet 1 of 2)

	σ^c_m, psi	ϵ^c_m, %	E_o, psi
$\overline{X}$	139.0	32.2	918.7
S_X	22.6	5.16	390
n = 46			

Statistics without aged fuel premix

	σ^c_m, psi	ϵ^c_m, %	E_o, psi
$\overline{X}$	130.4	33.54	766.5
S_X	15.7	4.85	256
n = 37			

Production Run No.	400-gal Batch	Maximum Corrected Stress, psi	Maximum Corrected Strain, %	Initial Tangent Modulus, psi
N/A	1450	120	31	1,229
1	1454	126	43	408
1	1455	128	40	587
1	1456	123	40	432
1	1457	115	37	658
1	1458	90	28	312
1	1459	118	37	399
1	1460	131	40	393
1	1461	131	38	460
1	1462	120	40	526
1	1463	107	32	411
1	1464	110	38	555
1	1465	135	33	468
2	1468	133	29	999
2	1469	137	29	1,081
2	1470	141	35	833
2	1471	126	29	779
2	1472	122	24	967
2	1473	121	25	925
2	1474	124	32	720
2	1475	114	29	846
2	1476	120	27	570
2	1477	112	30	740
2	1478	127	34	572
2	1479	117	25	816
3	1480	160	31	844
3	1481	149	33	933

TABLE 45. UTP-18,803A ICRPG CLASS B PHYSICAL PROPERTIES
0.85 NCO/OH RATIO
(Sheet 2 of 2)

Production Run No.	400-gal Batch	Maximum Corrected Stress, psi	Maximum Corrected Strain, %	Initial Tangent Modulus, psi
3	1482	156	32	1,092
3	1483	135	31	1,036
3	1484	147	38	880
3	1485	145	36	1,124
3	1486	152	37	1,100
3	1487	144	37	1,000
3	1488	142	37	918
3	1489	142	31	1,104
3	1490	151	35	808
3	1491*	154	38	836
2A	1495*	172	26	1,605
2A	1496*	169	24	1,666
2A	1497*	166	24	1,764
2A	1498*	179	29	1,577
2A	1499*	181	28	1,536
2A	1500*	177	28	1,479
2A	1501*	174	28	1,444
2A	1502*	172	25	1,482
2A	1503*	180	31	1,346

* Aged fuel premix

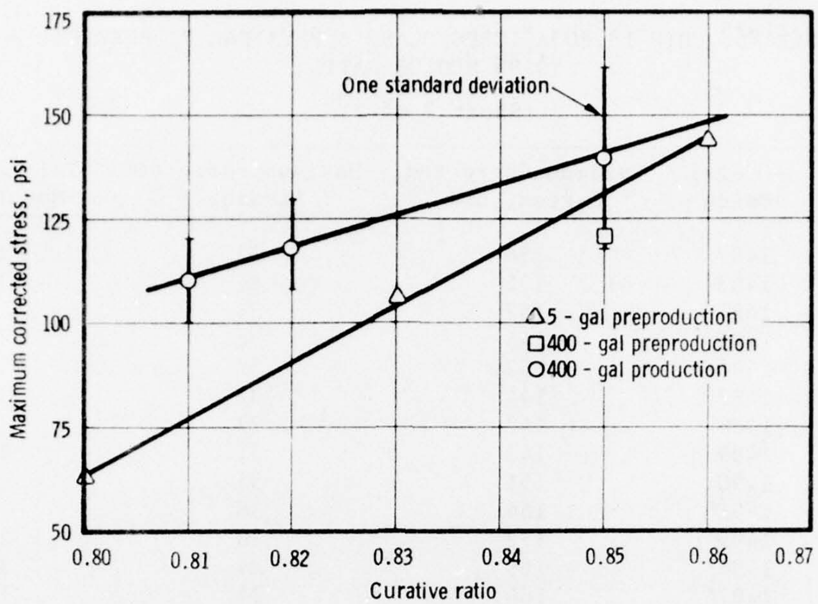


Figure 68. Maximum Corrected Stress vs Curative Ratio

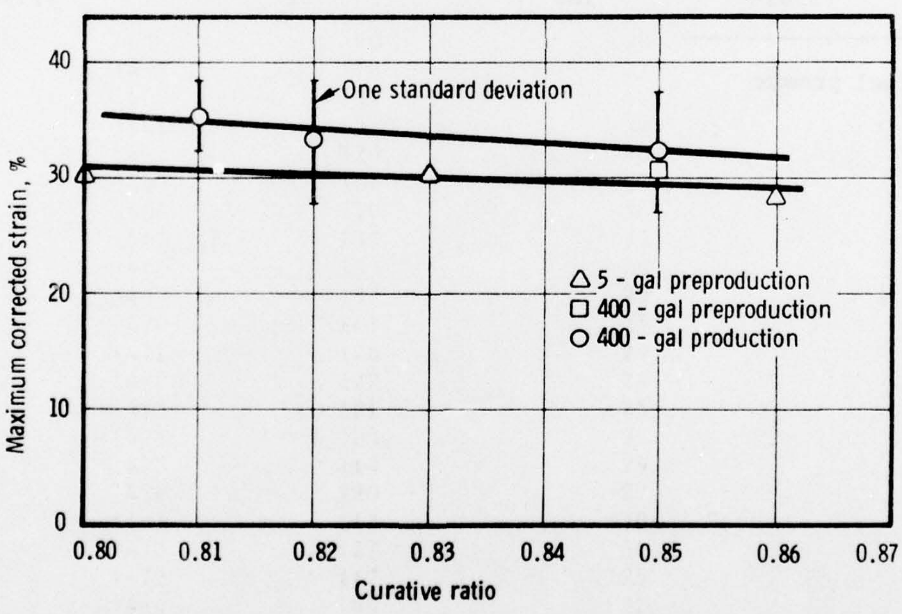


Figure 69. Maximum Corrected Strain vs Curative Ratio

6.0 CONCLUSIONS

The ability to process reproducible high solids loaded HTPB propellants under production conditions has been demonstrated.

A. Propellant Processing

1. Procedures and controls for processing UTP-18,803A as a production propellant have been demonstrated and documented (appendices B through G).
2. Production of 90% solids, 21% aluminum HTPB propellants is now state-of-the-art technology.
3. Use of fuel premix as a means of minimizing batch mix time is a realistic approach and the limits of its use (e.g., aging) are known for UTP-18,803A.
4. Batch processing times of approximately 3 hr have been demonstrated to provide adequate mixing.
5. The ability to cast up to five batches in a motor without affecting the setup (i.e., curing, bonding between propellant and cartridge and between batches) of the initial batch by entrainment of the subsequent batches was demonstrated.

B. Propellant Burning Rate

1. UTP-18,803A exhibits no significant burning rate change due to motor size (4-lb vs 84-in. CHAR).
2. UTP-18,803A exhibits no significant burning rate change due to mixer size (5-gal vs 400-gal).
3. Burning rate control by using the AP particle weight mean diameter (both ground and unground) was demonstrated to be a feasible approach.
4. Burning rate reproducibility of UTP-18,803A exceeded that published for Minuteman and is comparable for the lower solids-loaded propellants used for Titan and Algol.

C. Mechanical Properties

1. UTP-18,803A exhibits mechanical properties far in excess of those required for loading, curing, shipping, and testing 84-in. cartridges.
2. Analog simulations with UTP-18,803A did not induce failure in the propellant/cartridge bond, even at temperatures of -60°F after 2-year propellant aging.

ACRONYMS

AFPRO	Air Force Plant Representative Office
AFRPL	Air Force Rocket Propulsion Laboratories
AP	ammonium perchlorate
AQL	acceptable quality level
B/A	grain OD/grain bore diameter
BIT	bond-in-tension
B/P	blueprint
CIV	critical impact velocity
CSBR	cured strand burning rate
CSD	Chemical Systems Division
CTPB	carboxy-terminated polybutadiene
DDI	dimeryl diisocyanate
DoT	Department of Transportation
ELSH	extended length Super HIPPO
EOM	end of mix
GFE	Government-furnished equipment
HA	half angle
HIPPO	high internal pressure producing orifice
HTPB	hydroxy-terminated polybutadiene
ICBM	intercontinental ballistic missile
ICRPG	Interagency Chemical Rocket Propulsion Group
ID	inside diameter
IDP	iso-decyl pelargonate
IDR	integrated discrepancy report
IPDI	isophorone diisocyanate
IQOP	integrated quality and operations procedures
L/D	length-to-diameter (ratio)
LSBR	liquid strand burning rate
MC	motor conditions
MEOP	maximum expected operating pressure
MRB	material review board

NBR	nitrile butadiene rubber
NCO/OH	propellant curative ratio
NWS	Naval Weapons Station
OD	outside diameter
O&QR	operations and quality record
ORCO	Ohio Rubber Company
PCO	procuring contracting officer
PEPCON	Pacific Engineering
P/N	part number
QA	quality assurance
QC	quality control
SEC	strain evaluation cylinder
SLSH	short length Super HIPPO
S/N	serial number
SOW	statement of work
TVC	thrust vector control